SYNCHRO – SERVO FUNDAMENTALS

TRAINEE'S GUIDE

for

MAINTENANCE TRAINING

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SYNCHRO-SERVO FUNDAMENTALS
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1. This publication has been prepared for use as a text in Class "A" schools for Navy technicians and other schools as appropriate. The Instructor's Guide, NavPers 92390, is the complementing text for this course.

2. Corrections and recommendations for changes to this publication are invited. The Commanding Officer, Service School Command, San Diego, California, has been assigned clearing house responsibility for evaluating and compiling recommended improvements, and for submitting them to the Chief of Naval Personnel in the form of a proposed change. Users of this course material are requested to submit their recommendations directly to the command having clearing house responsibility with a copy to the Chief of Naval Personnel (Attn: Pers-C1123).

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SYNCHRO AND SERVO FUNDAMENTALS

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SAFETY NOTICE

WARNING

The attention of all hands is directed to Section V, Chapter 67 of Bureau of Ships Technical Manual or superseding instructions on the subject of safety.

Extreme caution must be observed when working with fire control systems and associated equipments for, as a rule, dangerous voltages are present. Contact with such voltages can result in permanent injury or death. While every practical safety feature is incorporated into Navy equipments presenting potential hazards to personnel, it is still necessary to exercise every caution when working with them. Following are basic rules which must be strictly observed by maintenance personnel.

KEEP AWAY FROM LIVE CIRCUITS:

Operating personnel must at all times observe all safety regulations. Do not change components or make adjustments inside equipments with the high-voltage supply ON. Under certain conditions, dangerous potentials may exist in circuits with the power controls in the OFF position. Such a condition is presented when capacitors retain charges. To avoid casualties, it is thus necessary not only to remove power but also to discharge and ground circuits prior to touching them.

DO NOT SERVICE OR ADJUST ALONE:

Under no circumstances should any person reach within or enter the enclosure of (for the purpose of servicing or adjusting) the equipment without immediate presence or assistance of another person capable of rendering aid.

DO NOT TAMPER WITH INTERLOCKS:

Do not depend upon door switches or interlocks for protection; always shut down motor generators or other equipment. Under no circumstances should any access gate, door, or safety-interlock switch be removed, short-circuited, or tampered with in any way (other than for replacement) without the specific authority of the Bureau of Ships. Personnel must not rely upon the interlock switches to remove dangerous voltages from the equipment. Periodic tests and inspections must be made on these devices to ensure that they are operating correctly.

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RULES REGARDING CIRCUITS EMPLOYING 300 VOLTS OR MORE:

Voltages in excess of 300 volts shall not be measured by probing or holding the test probe in the hands. Whenever measurements are necessary on equipment employing potentials in excess of 300 volts or where rubber gloves cannot be worn, the following precautions and procedures shall be observed:

1. The equipment shall first be deenergized.
2. High voltage capacitors shall be discharged with a suitably insulated shorting or grounding bar.
3. The technician shall ascertain that test equipment controls are set correctly for testing high voltage.
4. Test leads capable of carrying high voltage shall be secured on the desired test point by the technician.
5. The technician shall withdraw the equipment under test, making sure that he is also free from leads and in a good position for making correct meter readings.
6. The equipment shall be energized by an assistant standing by the switch.
7. After the necessary reading is made, the equipment shall be deenergized and high voltage capacitors shall be discharged.
8. The foregoing steps shall be repeated as necessary for each measurement.

GENERAL NOTES (WHICH CAN SAVE YOUR LIFE):

Make certain that you are not grounded whenever you are adjusting equipment or using measuring equipment. In general, use only one hand when servicing live equipment.

If the test meter must be held or adjusted while voltage is applied, ground the case of the meter before starting measurement; do not touch the live equipment while you are holding the meter. Some moving-van-type meters should not be grounded; thus, they should not be held during measurements.

Do not forget that high voltages may be present across terminals that are nominally low voltage due to equipment malfunction or breakdown. Be careful even when measuring low voltages.

Do not use test equipment known to be in poor condition.

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GENERAL NOTES (WHICH CAN SAVE YOUR LIFE) (Continued)

High voltage, high capacity capacitors should be discharged with an insulated shorting or grounding bar with approximately 10 ohms in series with the grounded line.

Where neither terminal of a capacitor is grounded, short the capacitor terminals together.

Take time to be safe.

RESUSCITATION

Approved posters illustrating the correct procedures and listing rules for resuscitation must be displayed prominently in each radio, radar, or sonar enclosure. These posters may be obtained upon request to the Bureau of Medicine and Surgery. Formerly, manual methods of artifical respiration were used exclusively. These methods include the prone pressure method, the hip lift-back pressure method, the arm lift-chest pressure method, the arm lift-back pressure method, and Eve's method (rocking on a stretcher). More recently, the "rescue breathing" methods have come into prominent use. These latter methods represent the most efficient means of resuscitation without the use of special equipment, and include mouth-to-mouth, mouth-to-nose, and mouth-to-mouth-and-nose techniques.

Mouth-to-mouth resuscitation is accomplished by sealing one's mouth over the patient's mouth, pinching the nostrils shut, and blowing until his chest lifts — an indication that his lungs are filled with air. The air is then allowed to escape, and the procedure is repeated at the normal rate of breathing until the patient can breath for himself.

Resuscitation using the patient's nose for an airway is as satisfactory as the mouth-to-mouth method. It is the method preferred by many. When this method is used, the patient's mouth is held closed as air is blown into the nose.

Both the nose and mouth may be used as the patient's airway. This method is, in fact, quite often used when administering resuscitation to infants.

SUMMARY OF STEPS USED IN RESCUE BREATHING:

1. Start the process immediately.
2. Place the patient on his back.
3. Clear the mouth and throat of debris.
4. Tilt the patient's head back.
5. Pull the patient's chin forward, using the middle fingers, so that the lower jaw is literally lifted and it "juts out." This step is necessary to keep the tongue out of the air passage. The lifting is accomplished by placing fingers beneath the jawbone and behind it on a line almost perpendicular to the ear. Using one hand, hold the jaw in this position.
6. Blow air through mouth or nose (or both) until chest rises. (Nostrils should be pinched with fingers if mouth-to-mouth method is used.)
7. Remove your mouth and listen for snoring and gurgling—signs of throat obstruction. If the throat is obstructed, turn the patient quickly on his side and administer several blows between the shoulder blades in an effort to dislodge the obstruction.
8. The complete cycle of filling the patient's lungs with air and allowing them to deflate should be smooth, with each complete cycle starting at approximately five-second intervals.
9. Continue rescue breathing until the patient breathes for himself.

1. Thrust head backward.

2. Lift tongue and jaw.

3. Pinch nostrils.

4. Blow into patient's mouth.

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SUMMARY OF STEPS USED IN RESCUE BREATHING: (Continued)

Although rescue breathing is the preferred method for administering artifical respiration, the technician should be skilled in other methods in order to manage situations where rescue breathing cannot be used. The method to be used is dictated by the condition of the patient, the availability of equipment and trained personnel, and the particular environment.

There are procedures applicable to all methods of resuscitation. The first thing is to begin immediately by putting the patient in the proper position. Do not wait for help or equipment. Since every second counts, start the resuscitation and attend to secondary measures as you proceed. The important thing is to establish and maintain the rhythm of artifical respiration without interruption. Matters such as clearing debris from the mouth, pulling out a swallowed tongue, keeping the area about the mouth clear so that no foreign matter is taken in, loosening clothing which restricts breathing, removing wet clothing and keeping the patient warm are vital, but they should be done without interrupting the rhythm.

The patient should not be given any food or liquid until he is fully conscious. The artifical respiration should be performed on the scene if possible. Once breathing is restored, the patient should be transported on a stretcher for further medical attention.

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HOW TO USE THIS TRAINEE'S GUIDE

TECHNICAL TRAINING

This Trainee's Guide has been prepared to place emphasis on the practical training of the technician in the operation and maintenance of equipment which contains synchros and servos. All Navy technicians are craftsmen — not engineers or designers — and they will learn their skill by doing.

PUBLICATION

This publication is provided for your use while learning the theory, operation, and application of synchros and servos, and is intended for your retention at the end of this course. A quantity of blank pages have been provided so that you may place in this book any notes which will help you later for review or on the job aboard ship.

PRESENTATION OF COURSE MATERIAL

The presentation of course material on synchros and servos is divided into sections. Each section is further subdivided into topics. The material has been presented so that you will understand the operation of the components before you work with the circuits. You must make every effort to acquire the necessary knowledge and skills.

STUDY ASSIGNMENTS

Those study assignments not listed in this publication will be made by your instructor. Some time will be available for study during the regular school day, but additional study will be necessary. Assignments, covering the material to be discussed the following day, will normally be made at the end of the preceding school day.

RECORD OF CHANGES AND CORRECTIONS

No. or Description of Change	Made by	Date

SECTION 1

BASIC PRINCIPLES OF SYNCHROS

Topic No.	Topic Title	Page
1	Introduction to Synchros	2
2	Basic Principles of Synchros	14
3	Unit Construction of Synchros	26
4	Characteristics of Synchros	40

TOPIC 1: INTRODUCTION TO SYNCHROS

<u>You Are Now Going to Learn:</u>

1. Course organization and objectives.
2. What a synchro is.
3. Purpose of synchros.
4. Advantages of synchros.
5. Importance of synchros in Naval equipment.
6. Classification of synchros.
7. Schematic symbols for synchros.

<u>Discussion Points for This Topic Are:</u>

1. Left-hand rule of electron-current flow.
2. Origin of the name <u>synchro.</u>
3. Function of a synchro system.
4. Standard Navy synchros.
5. Prestandard Navy synchros.

ASSIGNMENT:

OP 1303 (First Revision), pages 1-3 and 54.
NAVPERS 10086-A, pages 120-122.

PURPOSE:

To become familiar with synchros, synchro systems, and synchro applications.

TOPIC 1: INTRODUCTION TO SYNCHROS

Course Organization and Objectives

Before taking the Synchro-Servo Fundamentals Course, the trainee will have completed basic electricity and electronics. These basic subjects included a study of transformers and magnetism, which will be reviewed briefly in this course because of their particular importance to the understanding of synchros.

Synchro and servo units are widely used in the Navy. They are not complicated and do not present a serious maintenance problem. The synchro-servo units and their associated systems, however, have been the source of numerous problems concerned with alignment and proper operation of the complex systems found in Navy ships today. These problems generally occur because of a lack of understanding of how the individual units operate and how to check their performance. This course is designed to provide the trainee with a good understanding of synchro and servo units, how they operate, how to maintain them, how to check them for proper operation, and how to make the required tests and adjustments.

United States Navy Synchros, Description and Operation, OP 1303 (First Revision), prepared by the Bureau of Naval Weapons, is used in conjunction with this Trainee's Guide. Therefore, study assignments will be given from OP 1303 (First Revision) as well as from the Trainee's Guide.

Simply reading about synchros and servos is not enough to secure a good working knowledge of these units. During the course, a Synchro Training Board, NavPers 70118, will be used to perform practical work on synchro units similar to those used in shipboard equipments. The Synchro Training Board contains three synchros, their interconnecting wiring, shafts, and gearing. All possible hookups and casualties can be simulated on the board.

Synchro-Servo Training Device, NavPers 70219, will also be used in conjunction with the Synchro Training Board to simulate the operation of a typical shipboard installation of a synchro-servo loop. This training device may also be used for casualty analysis of many of the encountered servo troubles.

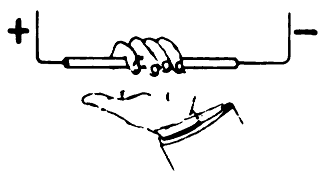
Course Organization and Objectives (Continued)

The course is presented in a logical sequence, starting with basic operating principles of synchros, their construction and characteristics, followed by their application, maintenance, and adjustments. Servo systems are introduced after synchros because, although they may include other units, most servo systems utilize synchros. The theory of synchros and servos will be supported by practical work on the Synchro Training Board and the Servo Training Device. The practical work will serve to demonstrate operating principles and to provide experience in tests, adjustments, and maintenance of the units.

NOTICE

THIS PUBLICATION WILL USE THE ELECTRON-CURRENT FLOW (LEFT-HAND RULE) AS TAUGHT IN THE COURSES ON BASIC ELECTRICITY AND ELECTRONICS. THE PRESCRIBED REFERENCE BOOK, OP 1303 (FIRST REVISION), AND THE TRAINING FILMS USE THE CONVENTIONAL FLOW (RIGHT-HAND RULE) IN ALL CASES. THEREFORE, THE TRAINEE MUST CONVERT TO THE LEFT-HAND RULE WHENEVER THE RIGHT-HAND RULE IS SHOWN. THIS CONVERSION FROM THE RIGHT-HAND RULE TO THE LEFT-HAND RULE CANNOT BE OVER-EMPHASIZED.

"USE THE LEFT-HAND RULE."



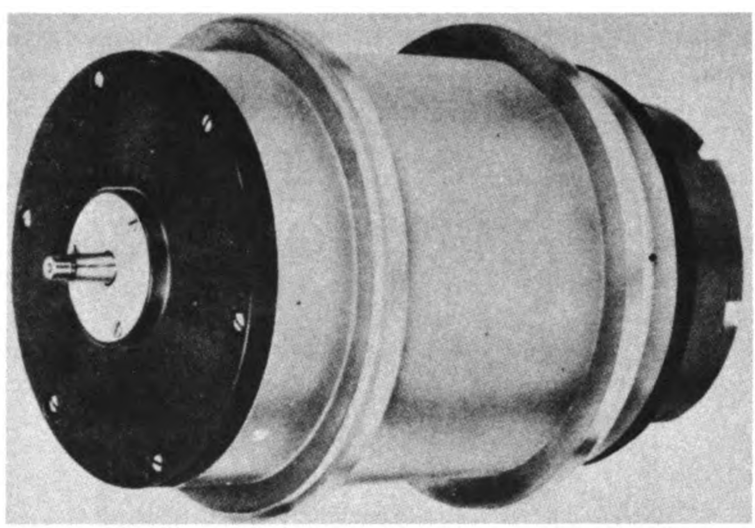
1. Left-Hand Rule

Course Organization and Objectives (Continued)

The illustrations and schematic diagrams used throughout this publication are exactly like the slides used by the instructor.

What a Synchro Is

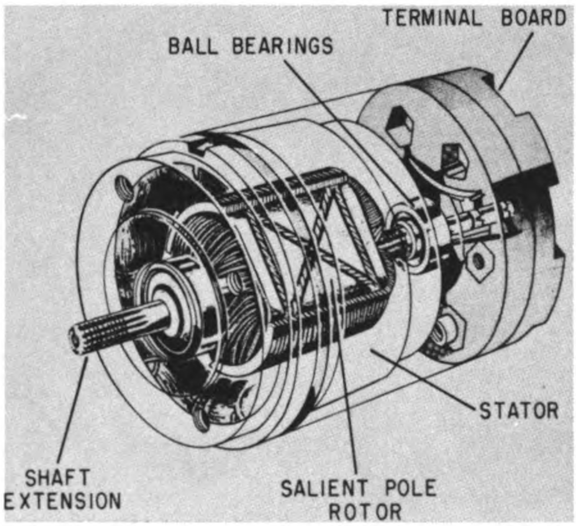
SYNCHRO is the name given to a wide variety of position sensing devices used to convert mechanical signals to electrical signals or to convert electrical signals to mechanical signals. The name synchro comes from the word synchronize, which means "to happen or take place at the same time." All synchros are self-synchronous; hence, the name is most descriptive of their basic action.



2. Typical Synchro

What a Synchro Is (Continued)

A synchro resembles a small electrical motor in size and appearance but operates like a variable transformer. Each synchro contains a rotor, similar in appearance to an armature, and a stator, which corresponds to the field in a motor. The synchro is usually composed of a three-winding, Y-connected stator encased in a cylindrical metal shield and a rotor with one winding. The rotor is mounted within the stator and is free to turn within the stator windings. As the one-winding rotor of a synchro is rotated, the amount of coupling in the three stator windings is varied, producing a variable voltage output that represents the amount and direction of displacement of the rotor from the stator.



3. Phantom View of a Synchro

The general construction and characteristics of virtually all synchros are similar, and the physical laws pertaining to the performance of synchros are similar; but the applications or the uses made of synchros vary considerably.

INTRODUCTION TO SYNCHROS

Purpose of Synchros

Synchros are position-sensing devices. The primary purpose of synchros is the precise and rapid transmission of data among equipments and stations. The change in course, speed, and range of targets or missiles, the angular displacement (position) of the ships rudder, the changes in speed and depth of torpedoes are but a few of the numerous kinds of data which must be transmitted, evaluated, and acted upon in a minimum of time. Speed and accuracy of data transmission are most important. Without the position-sensing device known as the synchro, the offensive and defensive capability of the Fleet would be greatly limited. Navy ships, submarines, and airplanes rely on the synchro for rapid data transmission within and among equipments, such as computers, radars, missile launchers, turrets, etc., and the many remote locations where the information is required. In many cases, the data is presented as visual information and acted upon by operating personnel.

Advantages of Synchros

The transfer of accurate visual data between widely separated positions is the chief advantage in the use of synchros. At a remote station, a synchro system will provide continuous, accurate, and visual reproduction of important or need-to-know information originating at a control station.

Advantages of Synchros (Continued)

Among the many advantages of using synchros, the most important are:

1. Automatic data transfer between widely separated stations;

2. Good reliability, allowing minimum maintenance;

3. Small size, providing a significant saving in space and weight;

4. Wide adaptability without sacrificing precision.

Importance of Synchros in Naval Equipment

Before the advent of synchros in the Navy, step-by-step switches and motors were used in data transmission systems. Step-by-step switches were nothing more than motorized switches. This type of data transmission could develop large errors because of the space between switch positions. A few ships, which are equipped with DC generators only, must still use this type of data transmission. The importance of the smoother operating and more accurate synchro can be readily seen. Synchro systems in use in the Navy today are electrically accurate to 1/180 of a degree or 0.33 minutes of arc. Since electrical error is defined as the difference between the physical and electrical positions of the synchro rotor, synchro accuracy is usually expressed in minutes of arc.

Classification of Synchros

Synchros work in teams. Two or more synchros interconnected electrically form a synchro system. There are two general classifications of synchro systems: torque systems and control systems.

Synchro torque systems utilize torque synchros; synchro control systems utilize control synchros. The load dictates the type of synchro system and, consequently, the type of synchro:

light load: TORQUE SYNCHRO
heavy load: CONTROL SYNCHRO

Classification of Synchros (Continued)

TORQUE SYNCHROS are used for light loads such as the positioning of dials, pointers, or similar indicators. The positioning of these devices requires a relatively low torque.

A torque transmitter and a torque receiver make up a simple torque synchro system. These two synchros are electrically identical; however, they differ physically. The torque receiver contains an inertia damper; the torque transmitter does not. Because of this significant physical difference, the two types of torque synchros are not mutually interchangeable. A torque receiver could be substituted for a torque transmitter; but, if a torque transmitter were substituted for a torque receiver, lack of an inertia damper would probably cause the transmitter to oscillate.

CONTROL SYNCHROS are used in systems designed to move heavy loads such as gun directors, radar antennas, and missile launchers. The type of system using control synchros is a servo system; the synchro systems maintain control while the servomechanisms provide power to do the heavy work. Control synchros are always used when an electrical output is needed.

A control transmitter and a control transformer make up a simple synchro control system within a servo system. These units cannot be indiscriminately interchanged because the control transmitter is not capable of damping action.

In addition to the two general classifications, torque and control, synchros are grouped into seven basic functional classes. Four of these functional classes are of the torque type and three are of the control type.

A torque transmitter is normally used in a torque system only. Its function is to convert mechanical information into electrical information and to transmit this information. The torque transmitter may sometimes be used as a control transmitter but only where accuracy is not too important.

Classification of Synchros (Continued)

A torque differential transmitter electrically transmits the algebraic sum or difference of an electrical and a mechanical input.

A torque receiver is a synchro which receives an electrical input to its stator, causing its rotor to duplicate physically the position of the transmitter's rotor.

A torque differential receiver supplies a mechanical output from its rotor shaft whose physical position represents the algebraic sum or difference of two electrical inputs.

A control transmitter performs the same basic function as a torque transmitter but is used only in synchro control systems.

A control differential transmitter is functionally the same as a torque differential transmitter but is used only in synchro control systems.

A control transformer produces one electrical output for one electrical input. The electrical output of the rotor winding is proportional to the sine of the angular difference between rotor position and the electrical input to the stator.

Technical advances in recent years require that still another classification be made: "operating frequency." During the early development of synchros, Navy ships had only DC power; later came AC power at 60-cycle frequency. The relationship of frequency to power dictated the practical size of the synchro. During the past decade, the need for smaller components, primarily in aviation, led to the development of 400-cycle synchros. The development of these smaller components, which save space and weight without sacrificing power or precision, signaled a sweeping change in many fields. In new equipment, 400-cycle synchros are used instead of 60-cycle units. Although higher frequencies permit smaller physical size, some 400-cycle synchros are being manufactured to fit existing 60-cycle mountings in order to reduce the costs involved in conversion.

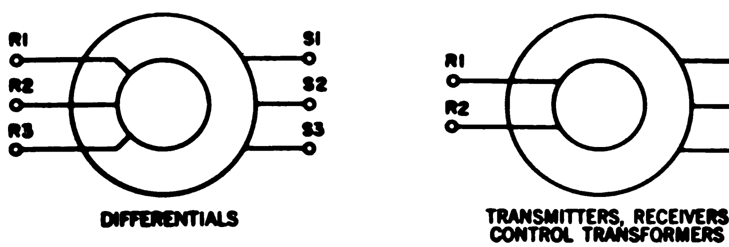
Types of Synchros

Synchros are further subdivided into many types and sizes, both prestandard and military standard.

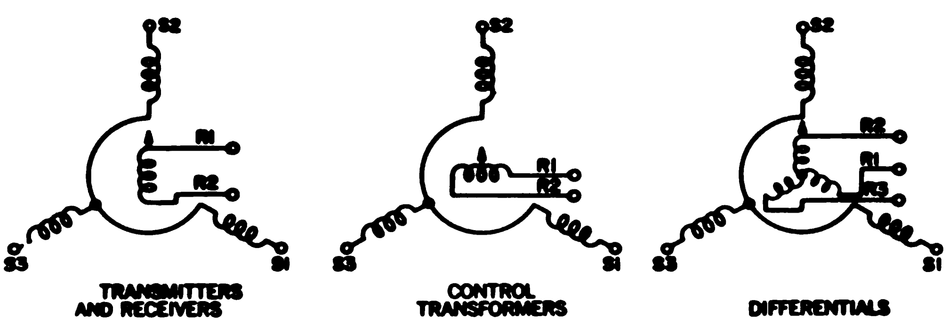
Prestandard synchros are those synchros which were manufactured for the Navy before the unification of the supply system for all the armed forces. Standard synchros, used in all new equipments, are manufactured to meet service-wide specifications. (Refer to OP-1303, First Revision, chapter 4, for the numbering method and description of prestandard and standard synchros.)

Schematic Symbols for Synchros

Schematic symbols for synchros are drawn by their manufacturers in many different ways. Only five symbols, however, meet the standard military specifications for schematic diagrams of synchros and synchro connections. Appearing close to the symbol may be a military abbreviation of one of the seven functional classifications of synchros. If the synchro is bearing-mounted, a suffix B will be added to this abbreviation.



4. Schematic Symbols Used to Show External Connections Only



5. Schematic Symbols for Relative Positions of Windings

Schematic Symbols for Synchros (Continued)

Accurate data transmission, both visual and control, between widely separated positions will be one of the prime responsibilities of all men in electrical and electronic Naval ratings. Complete familiarization with synchros and their supporting units cannot be overemphasized. An exact knowledge of how synchros work and their function in a servo loop is required to maintain circuits and to trouble-shoot casualties.

Summary

Electron-current-flow theory will be used in this publication. The reference publication OP 1303 (First Revision) and the training films to be used in this course use the conventional-current-flow theory (right-hand rule). The trainee must convert to the left-hand rule in all cases where the right-hand rule is shown in other publications. Use the left-hand rule of electron-current-flow.

The name synchro comes from the word synchronize. SYNCHRO is the name given to a wide variety of electromechanical devices resembling small electrical motors.

Synchros are position-sensing devices whose primary purpose is the rapid and precise transmission of data among equipments and stations.

Automatic data transfer between widely separated stations and good reliability with little maintenance required are two of the many advantages of the use of synchros.

Synchro systems in use in the Navy today are accurate to 1/180 of a degree or 0.33 minutes of arc. Accuracy of a synchro is usually expressed in minutes of arc. This accuracy is the difference between the physical and electrical position of the rotor of a synchro.

Two general classifications of synchro use are the torque system and the control system. Torque systems provide a mechanical output, and control systems provide an electrical output.

Summary (Continued)

All synchros are grouped into seven functional classes, four torque type and three control type.

Still another classification has been necessary in recent years: 60 cycle or 400 cycle.

Generally, higher frequency units may be made smaller than lower frequency units without sacrificing the power of the unit.

Synchros are further subdivided into many types and sizes, both prestandard and military standard.

Only five schematic symbols for synchros are acceptable according to standard military specifications.

TOPIC 2: BASIC PRINCIPLES OF SYNCHROS

<u>You Are Now Going to Learn:</u>

1. Effects of magnetism and electromagnetism.
2. Characteristics of AC and DC electromagnets.
3. How to position a bar magnet with an electromagnet.
4. Theory of transformer action.
5. How frequency of excitation affects physical size.

<u>Discussion Points for This Topic Are:</u>

1. Natural magnets, artificial magnets, and electromagnets.
2. Flux density or field strength.
3. Transformer ratio and turns ratio.
4. Primary windings and secondary windings.
5. Induced voltages.

ASSIGNMENT:

OP 1303 (First Revision), pages 4-11.

PURPOSE:

To learn the similarity between the basic principles of electromagnetism and transformer action and the basic principles of synchros.

TOPIC 2: BASIC PRINCIPLES OF SYNCHROS

Magnetism

Knowledge of the basic principles of magnetism and electricity is essential in order to understand the basic functions of synchros and servos; therefore, a brief review of magnetism and electricity will be of practical value for maintaining these electromechanical units.

Magnetism is the property of attraction that one mass or body has for another mass or body. The north-seeking ability of a compass needle is an example of magnetic attraction between two bodies.

One of the more common examples of a body having magnetic properties is the magnet. There are three classes of magnets: natural magnets, artificial magnets, and electromagnets.

Natural magnets come from natural deposits of loadstone or certain iron oxides found in various places about the earth. These deposits possess natural magnetic properties, hence the name "natural magnet."

Artificial magnets are manmade, usually from a hard steel alloy having very low permeability but high residual magnetism. This means that the hard steel alloy is reluctant to become magnetized, but once it becomes magnetized, it remains so for such a long period of time that it is effectively permanently magnetized.

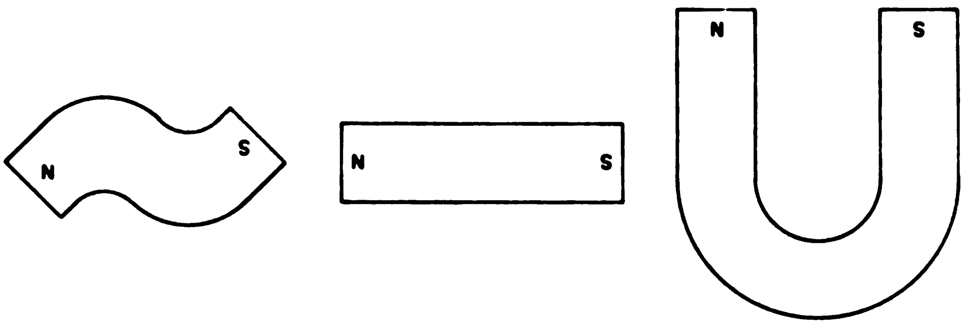
Electromagnets are made by wrapping a coil of wire around a soft iron core. When electricity is passed through the coil, the soft iron core becomes magnetized. The more current passed through the coil, the more strongly the core becomes magnetized.

Magnetism is a property of matter. Any object having this property can be called a magnet. Magnets have two poles, defined as a north pole and a south pole. One basic law of magnetism is that like poles repel, unlike poles attract. Because magnets have a north pole and a south pole, and because these are unlike poles, an attraction is always present between the two poles of any magnet.

Magnetism (Continued)

A magnetic field is, therefore, composed of many lines of magnetic force. The area immediately around a magnet is the strongest part of that magnet's field. The maximum strength, or flux density, of the field is concentrated around the poles of the magnet.

Magnets can be formed into many shapes; horseshoe, bar, and S-shaped are a few examples. The bar magnet is the one used to demonstrate the function of a synchro rotor.



6. Magnet Shapes

Electromagnetism

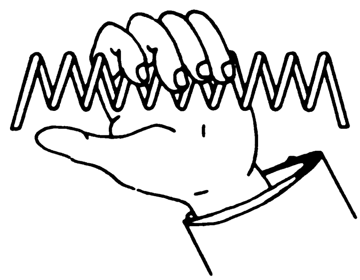
An electromagnetic field is developed around a current-carrying conductor. This field exists only while current is flowing. The amount of current passing through the conductor is a factor of field strength: the more current, the more field strength. Shape of the conductor is another factor of field strength. Forming the conductor into a coil will increase field strength because lines of force from one turn will combine with lines of force from adjacent turns. Increasing the number of turns in the coil will also increase field strength. Inserting a soft iron core in the center of the coil is another way of increasing field strength.

Thus, a strong electromagnetic field will result when a large value of current is passed through a coil having a large number of turns and a soft iron core.

Direct Current Electromagnets

A solid iron core is used in direct current (DC) electromagnets.

The direction of the lines of force built up in a magnetic field may be determined by the left-hand rule. If the thumb is pointed in the direction of electron flow and the fingers are curved around the conductor, the fingers point in the direction taken by the lines of force in the magnetic field. The fingers will also point in the same direction as the north-seeking needle of a compass placed in the magnetic field.



7. Magnetic Field around Coil

Alternating Current Electromagnets

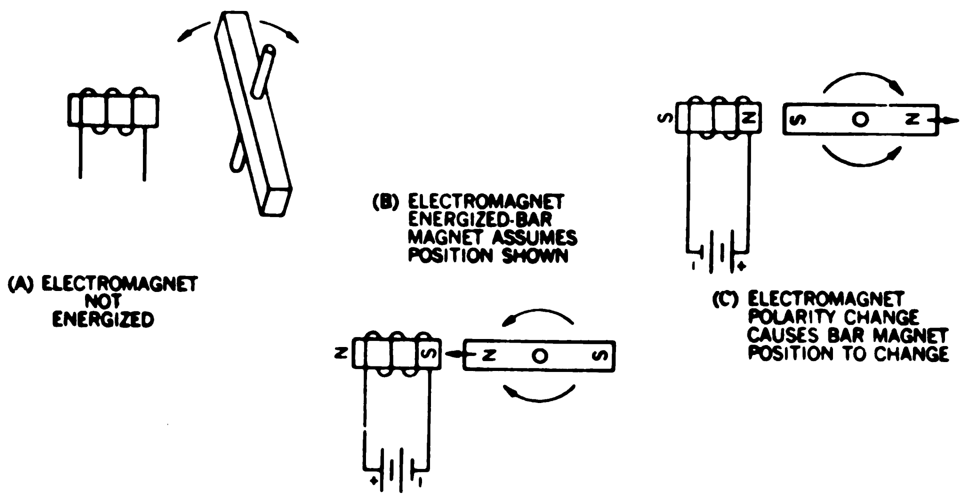
Alternating current (AC) electromagnets use the same type of coil as DC electromagnets, but, instead of a solid soft iron core, AC electromagnets use laminated iron cores or a bundle of soft iron wires. A solid, soft iron core is not used because the eddy currents set up by the alternating current would cause a loss in the strength of the magnetic field. Instead of being limited by the current-carrying capacity of the winding, the flux density is determined almost entirely by the inductive reactance of the coil to the laminated soft iron core. The pull of an alternating current magnet is nearly constant because of the self-induction (counter EMF) which tends to maintain the current flow.

Positioning Bar Magnet with Electromagnets

In part A of the accompanying illustration, a bar magnet is mounted near an electromagnet. While the electromagnet is not energized, the bar magnet is free to turn or to come to rest in any position.

Part B of the illustration shows the effect upon the bar magnet of energizing the electromagnet. The bar magnet is forced to assume one specific position in relation to the magnetic field of the electromagnet.

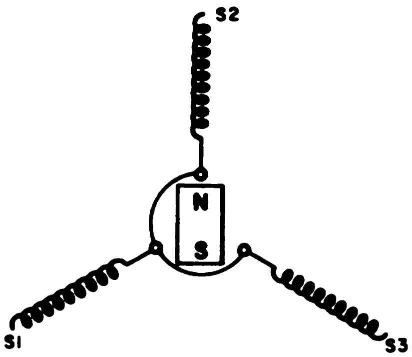
Hence it follows that when the polarity of the electromagnet is reversed, the position of the bar magnet must also reverse. Part C of the illustration shows this reversal.



8. Positioning Bar Magnet with One Electromagnet

Positioning Bar Magnet with Electromagnets (Continued)

Visualize three, identical, coiled electromagnets, Y-connected 120° apart around a permanent bar magnet. The electromagnets are securely fastened to a mounting, and the permanent bar magnet is mounted so that it can turn freely. If the same voltage is applied to all three of the electromagnets, one combined magnetic field will result. This will cause the bar magnet to align itself with the magnetic field at the point of greatest flux density or field strength. This position will be in line with one coil, bisecting the angle between the other two coils. If the phase of the voltage applied to one of the electromagnetic coils is changed, the flux density of that particular coil will be changed. The magnetic field of the three coils will change accordingly, and the position of the bar magnet will change to align itself with the new point of greatest flux density.



9. Three Identical Electromagnets Mounted Around a Bar Magnet

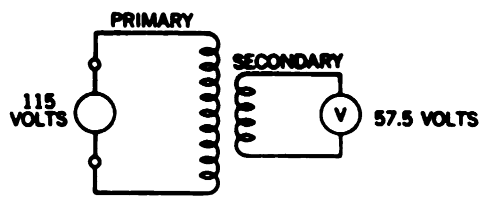
Small voltage changes in the three equally-spaced electromagnets will allow an infinite number of positions for the bar magnet.

Review of Transformer Theory

The fact that an AC source fluctuates is the basic principle behind the operation of a transformer. A simple transformer consists of two parallel windings separated by a small gap so that the fluctuation of the magnetic field in the primary winding will induce a voltage into the secondary winding. Induced voltage is dependent upon the turns ratio between the primary and secondary windings, the voltage applied to the primary winding, and the angular physical displacement of the secondary winding from the primary winding. The frequency of fluctuation does not change from the primary winding to the secondary winding.

Review of Transformer Theory (Continued)

The transformer ratio is the ratio between the applied voltage in the primary winding and the induced voltage in the secondary winding. The primary-to-secondary turns ratio (that is, the ratio of the number of turns in the primary winding to the number of turns in the secondary winding) will give a close approximation of the transformer ratio. This approximation, however, is not precise. Transformer losses occur due to, for example, heat or iron and copper losses. These losses are compensated for by increasing the number of turns in the secondary winding to allow the transformer ratio to be expressed in terms of whole numbers. Being able to use whole numbers makes it very easy to calculate secondary voltage from a known transformer ratio and primary voltage.



10. An Example of a 2:1 Transformer Ratio

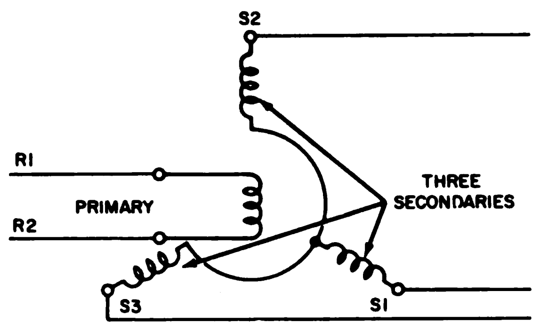
There are many types of rotatable transformers; synchros, tachometer generators, and resolvers are the most common. Either the primary winding or the secondary winding, or both, may be made rotatable.

A synchro transmitter-receiver has a one-winding rotor which is considered the primary winding and a Y-connected, three-winding stator which is considered the secondary winding.

Review of Transformer Theory (Continued)

When an AC voltage is applied to the rotor or primary winding of a synchro, a magnetic field is set up around the soft iron, laminated core of the rotor. This magnetic field induces voltage into the three Y-connected stator or secondary windings.

The angular displacement of the rotor from the reference position varies the induced voltage in each stator winding by an amount equal to the cosine of the angle of displacement. In other words, as the position of the rotor is changed in relation to the stator, the voltage induced in each stator winding varies as a function of the angular displacement of the rotor from the stator.



11. Transformer with One Primary Winding and Three Secondary Windings

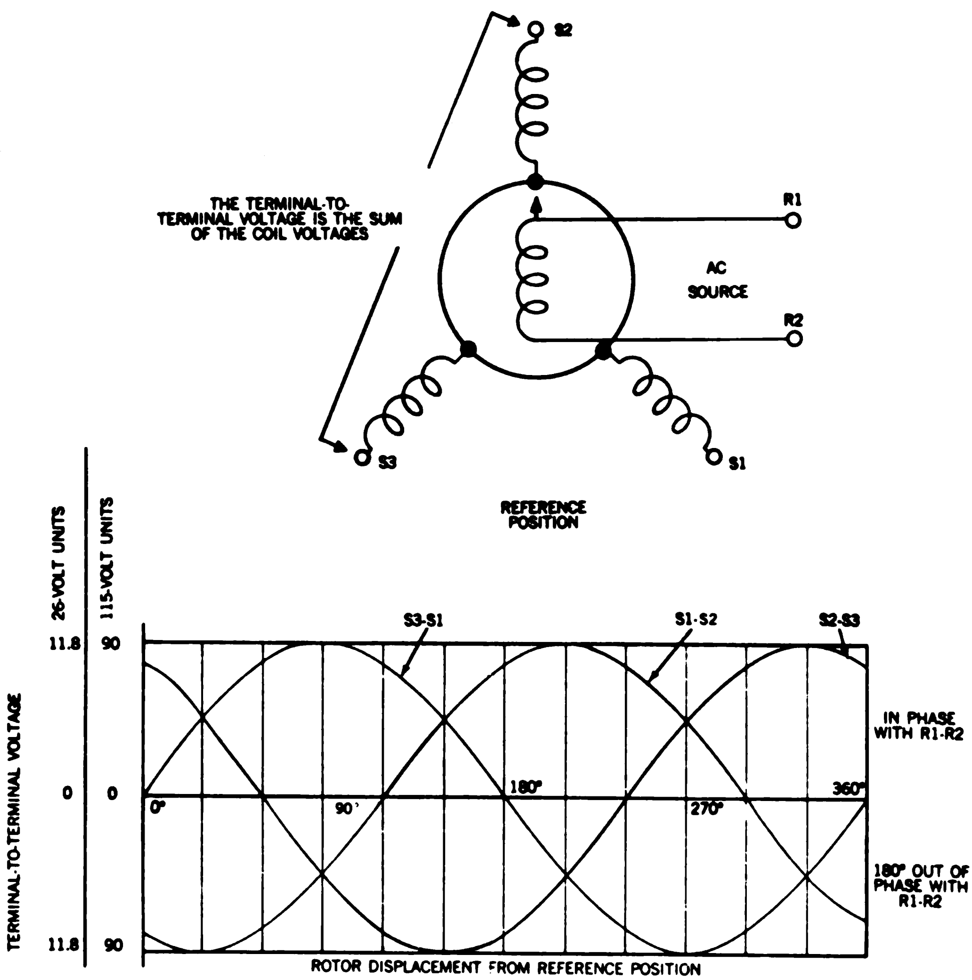
If the position of the rotor is parallel to one of the stator windings, maximum voltage will be induced into that winding. The voltages induced into the other two stator windings are then equal because their angles of displacement are equal.

The maximum voltage induced in any one stator winding from a 115-volt AC-excited rotor is 52 volts. This occurs only when the stator winding is parallel to the rotor. The voltage induced in one stator winding, however, cannot be measured because the common point of the three Y-connected windings does not appear as a terminal on the outside of the synchro case. Since the end terminals of the three windings are the only stator terminals that are led outside the synchro case, only the voltage induced in any two stator terminals can be measured.

Review of Transformer Theory (Continued)

The maximum voltage induced in any two stator windings from a 115-volt AC-excited rotor is 90 volts. This occurs only when the rotor is displaced 90° from the reference position. Whether the induced voltage is in phase or 180° out-of-phase with the excitation depends upon the direction of rotor movement from the reference position.

The following illustration shows the values of the three possible combinations of terminal-to-terminal stator voltages during one complete revolution of the rotor from the reference position.



12. Terminal-to-Terminal Voltages

Operating Frequencies

Synchros are like transformer-type units: the higher the designed operating frequency of a unit, the smaller that unit may be. If two synchros of equal power handling ability are built — one designed for 60-cycle excitation and one designed for 400-cycle excitation — the one designed for the higher frequency may be made physically smaller. This miniaturization is limited only by manufacturing and design capabilities.

The physical characteristics and construction of 60-cycle synchros and 400-cycle synchros are only similar. Lines of flux produced by the 400-cycle excitation are much more concentrated than those produced by 60-cycle excitation. Hence, the core size of the 400-cycle synchro can be made smaller than the core size of the 60-cycle synchro. If the number of turns in the rotor winding is reduced, the number of turns in the stator winding must be reduced accordingly. Because the transformer ratio is not changed, the power output of the smaller 400-cycle excited synchro can be the same as the power output of a 60-cycle excited synchro.

Space saving is important. Smaller synchros allow smaller indicating units, thereby saving space for other equipment. Aircraft space requirements brought about the first attempt to reduce the physical size of synchros. Now, 400 cycles is the predominant frequency specification for airborne equipment, while 60 cycles has remained the accepted specification for shipboard equipment. Ships, however, are beginning to use 400-cycle units because of their smaller size and lighter weight.

For flexibility in the use and supply of synchros, many 400-cycle synchros are supplied with a mounting adapter which permits them to be used to replace faulty 60-cycle synchros.

Summary

There are three classes of magnets: natural magnets, artificial magnets, and electromagnets.

Magnetism is the property of attraction that one body has for another body. Electromagnetism is magnetism developed by an electric current.

DC electromagnets have solid, soft iron cores; AC electromagnets have laminated iron cores.

Summary (Continued)

The amplitude of the voltage induced from the primary winding into the secondary winding of a transformer is dependent upon the amplitude of the primary voltage, the transformer ratio, and the angular displacement of the secondary winding from the primary winding.

Three, identical, coiled electromagnets, energized from a common source, Y-connected 120° apart, and mounted securely, develop an electromagnetic field. A rotatable bar magnet inserted at the center of the Y-connection will align itself with one of the coils and bisect the angle between the other two coils.

Lines of flux produced by 400-cycle excitation are much more concentrated than those produced by 60-cycle excitation. Thus, the core size of the 400-cycle synchro can be made smaller than the core size of the 60-cycle synchro. Hence, the number of turns in the rotor winding may be reduced. In order to maintain the original transformer ratio, the number of turns in the stator winding must be reduced accordingly. Thus, the 400-cycle and the 60-cycle synchros can produce the same power output while differing in size and weight.

STUDENT NOTES

TOPIC 3: UNIT CONSTRUCTION OF SYNCHROS

You Are Now Going to Learn:

1. General construction and physical appearance of synchro rotors and stators.
2. General construction and physical appearance of the following:

    a. Synchro transmitters.
    b. Synchro receivers.
    c. Synchro differential units.

Discussion Points for This Topic Are:

1. Salient-pole rotors.
2. Drum or slotted rotors.
3. Y-connected windings.
4. Bearings.
5. Sliprings.
6. Dampers.

ASSIGNMENT:

OP 1303 (First Revision), pages 12-20.

PURPOSE:

To become familiar with the physical construction of each type of synchro.

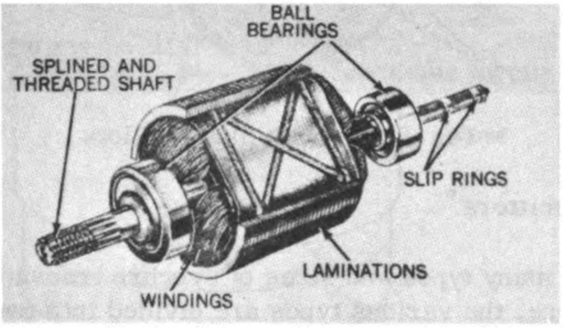
TOPIC 3: UNIT CONSTRUCTION OF SYNCHROS

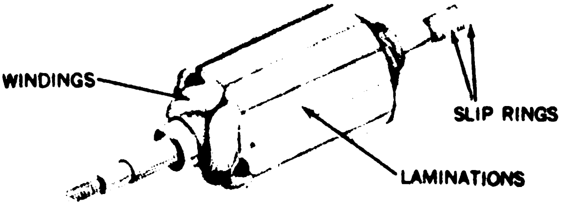
General Construction and Physical Appearance

Synchros and transformers have many common electrical characteristics, but the resemblance ends when physical appearance is considered. Although transformers are usually rectangular or square in shape, synchros are cylindrical,. from three to four inches long and usually about two inches in diameter. Some of the newer synchros are even smaller, only one inch in diameter and one-and-a-half inches long. Most synchros are painted flat black to help dissipate the heat generated by the excitation voltage.

The two main components of any synchro are the rotor and stator.

Rotor: The rotor, usually the primary winding of the unit, is mounted so that it is free to rotate inside the stator. The winding of the rotor is wound on sheet-steel laminations stacked together and securely mounted on a shaft. To enable the excitation voltage to be applied to this winding, two sliprings are mounted on one end of the shaft and insulated from it. An insulated terminal block, mounted on one end of the cylindrical frame, houses the brushes which ride on the sliprings. This terminal block and another insulated block that is mounted on the other end of the synchro frame contain low friction bearings that permit a rotation range from 0 to 1200 RPM.



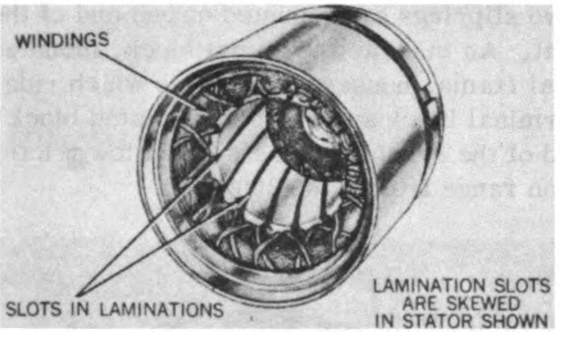


13. Salient Pole Rotor and Drum or Slotted Rotor

General Construction and Physical Appearance (Continued)

Stator: Mounted on the inside of the cylindrical shell of a synchro are three windings, Y-connected with their axes precisely 120° apart. The stator leads opposite the Y-connection are brought out of the cylindrical shell to an insulated terminal block and are labeled S1, S2, and S3. Rotor leads from the brushes, labeled R1 and R2, are also secured to this block.

The stator windings are wound on slotted laminations. These slots may be parallel to the rotor shaft centerline or may be skewed (slanted). When both the rotor and stator have slots, either the rotor or stator slots must be skewed in order to prevent "slot lock". Skewing sufficiently changes the pattern of flux concentration along the rotor shaft centerline to overcome the possibility of slot lock and, thereby, prevent angular errors due to slot lock.



14. Stator with Skewed Slots

Synchro Transmitters

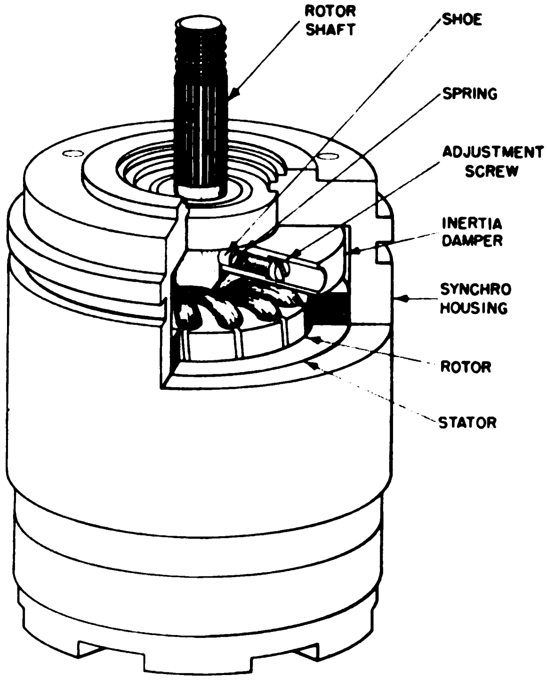
There are many types and sizes of synchro transmitters. As mentioned before, the various types are divided into two general use classes: torque type and control type.

The synchro transmitter, with an AC excitation on the rotor leads, produces a magnetic field around the rotor. The voltage induced into one winding of the stator will vary with the angular position of the rotor axis in relation to the stator windings. The operation of all synchros is based on this electromagnetic transformer action. A synchro transmitter is not interchangeable with a synchro receiver because the transmitter has no damping action and may, therefore, spin or oscillate when used as a receiver.

Synchro Receivers

When a synchro system is first energized, any sudden movement of the transmitter rotor can cause the synchro receiver to motorize (spin) or to oscillate about the point of synchronization unless some damping action is available to prevent this spinning or oscillation. The damping or retarding action is made available by shorting a winding on the quadrature axis positioned at right angles to the direct axis.

The quadrature-axis winding method of damping is not too effective, however, on large synchros. On larger synchro receivers, the oscillation or spinning is damped by a heavy flywheel mounted on the rotor shaft in such a manner as to oppose any sudden or jerky movements of the shaft. This heavy flywheel and its associated hardware is known as an inertia damper. Not all manufacturers mount this device in the same manner.

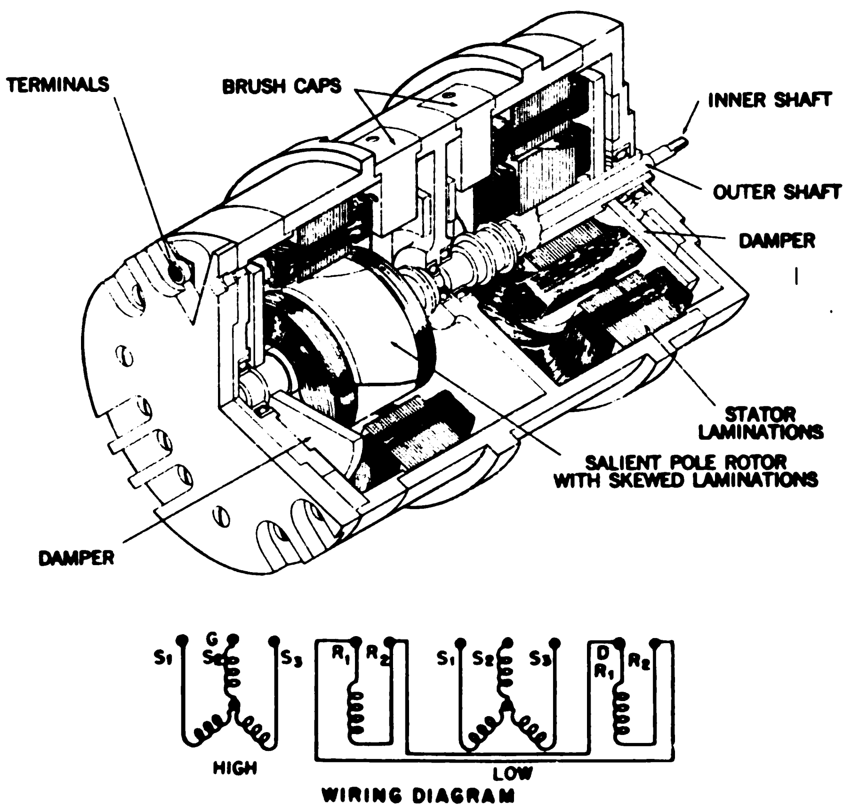


15. Cutaway View of Inertia Damper

Double Receivers

A double receiver is made up of one coarse and one fine receiver in a single case. Space restrictions have led to the development of two types of double receivers: the 2R double receiver and the control transformer. These two types of double receivers have the same physical appearance except for the emergent shaft.

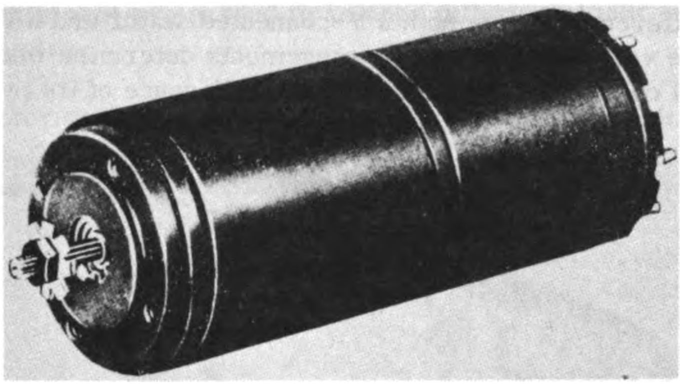
The type-2R double receiver has a two-shaft output, one inside the other, and is similar in operation to the hour and minute hands of a clock. The hour hand makes one complete revolution of the clock face while the minute hand makes twelve revolutions. The hour hand corresponds to the coarse receiver, and the minute hand corresponds to the fine receiver. This double receiver has the very definite advantage of requiring less space than two single receivers, but it also has a very definite disadvantage in that when one receiver goes bad both must be replaced.



16. Typical 2R Double Receiver

Double Receivers (Continued)

The second type of double receiver is a control transformer with a one-shaft output. This type has a low-speed rotor geared internally to a high-speed rotor; the output from the high-speed rotor appears on the two rotor leads as a control voltage for a servo motor.



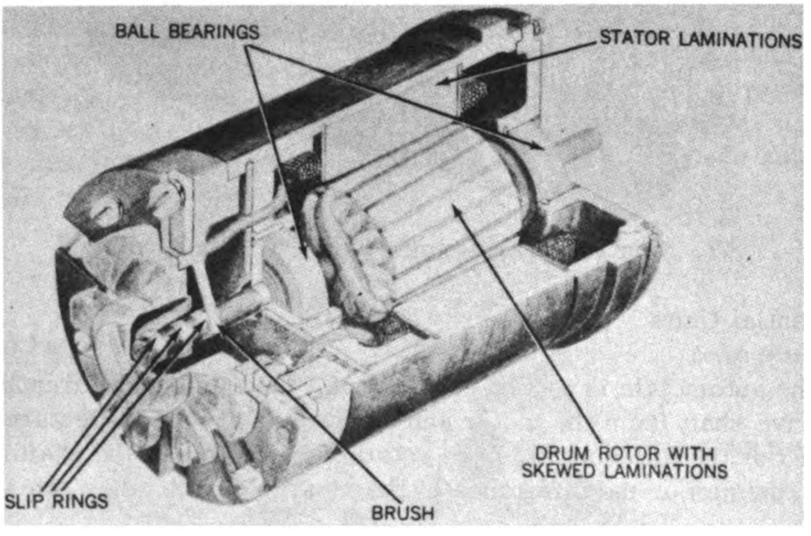
17. Control Transformer with One-Shaft Output

Differential Units

The automobile is a good example of a mechanical differential. The drive shaft from the motor and the two rear-wheel axles are geared together at the differential. The rotation of any one of the shafts is either the sum or the difference of the rotation of the other two shafts.

Differential Units (Continued)

Synchro differentials operate on the same principle as mechanical differentials but instead of two mechanical inputs, there is either one mechanical input (the rotor shaft) and one electrical input or two electrical inputs. Any combination of two of these three variables produces either the sum or the difference of the two at the third variable. Synchro differentials have both a Y-connected stator and a Y-connected rotor. The various connection arrangements determine whether the differential output will be the sum or the difference of its two inputs.



18. Typical Synchro Differential

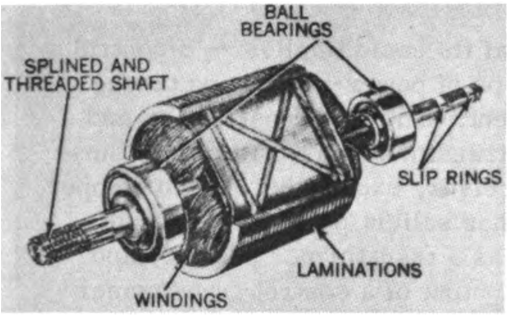
Differential Transmitters

Differential transmitters may be used in either torque synchro systems or control synchro systems.

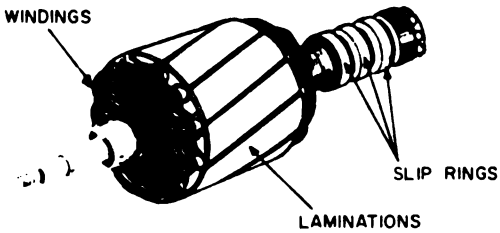
Differential Transmitters (Continued)

Most synchros use the rotor as the primary winding, but the synchro differential unit does not. The stator is usually the primary winding in a synchro differential. Excitation comes from the stator of a torque or control transmitter. Induced voltages in the rotor of the differential unit are passed to another differential unit or to a synchro receiver.

The rotor construction of a torque differential transmitter is different from that of a torque transmitter. Salient pole, single-winding rotors are used in most torque synchro transmitters and receivers; synchro differential units use the drum or slotted rotor for more precise control of the magnetic field. Three sliprings are needed in a synchro differential because of the Y-connected rotor windings.



19. Salient Pole Rotor



20. Drum or Slotted Rotor

Differential Receivers

Differential Receivers are an integral part of torque synchro systems; however, they are not normally used in control synchro systems.

The magnetic field resulting from two electrical inputs to a differential receiver causes the rotor to rotate to either the difference or sum of the two inputs. Whether the output is the difference or sum depends on how the rotor and stator of the transmitter units are connected to the synchro differential receiver.

Differential Receivers (Continued)

As with other receivers, damping action is needed. This is provided either by the heavy flywheel friction device mounted on the rotor or by a quadrature voltage winding on the rotor or stator.

Although the differential receiver acts as a transformer, neither the stator nor the rotor could be classed as the primary winding. Both sets of windings are AC excited with the rotor having a mechanical output to a pointer or dial indicator. The stator is normally connected to the closest or higher current rating transmitter.

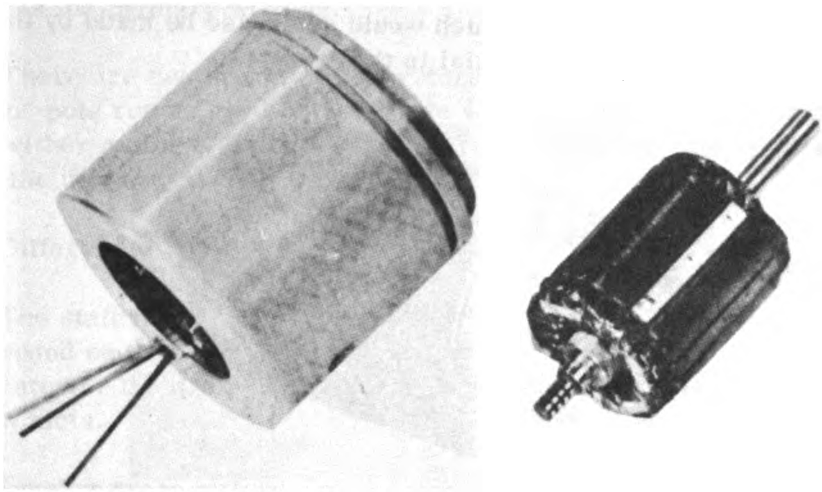
The one-to-one voltage ratio from the stator to the rotor of a synchro differential is achieved by inserting more turns on the rotor winding to compensate for transformer losses in the induced voltage.

Control Transformers

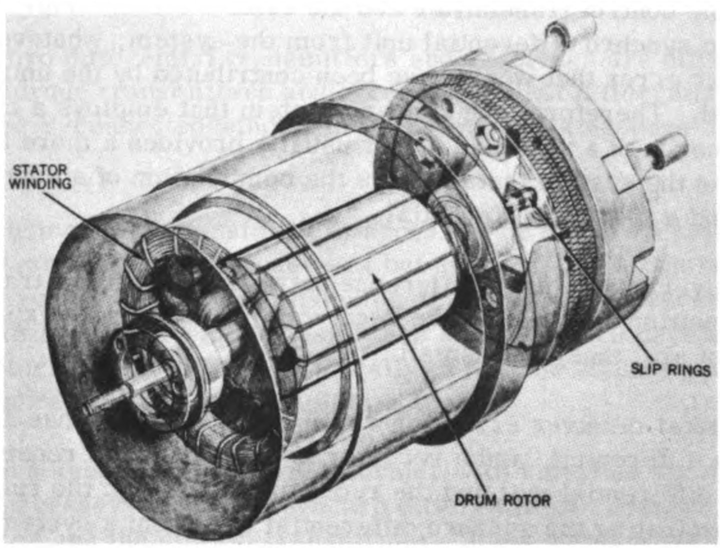
A control transformer is just what its name implies — a control device accurately controlling some type of power-amplifying device that is used for moving heavy equipment. The unit construction and physical characteristics of a control transformer are similar to those of a control transmitter or torque receiver, except there is no damper and the rotor is drum-wound rather than salient pole. In a control transformer, the stator windings act as a transformer primary and the rotor as a secondary. Thus, the output of a control transformer is taken from the rotor.

The electrical output from the rotor of a control transformer is an induced AC voltage whose amplitude and phase are dependent upon the angular displacement of the rotor windings from the magnetic field of the stator windings. When the rotor position is perpendicular to the magnetic field of the stator, the output of the control transformer will be minimum. Conversely, when the rotor position is parallel to the magnetic field of the stator, the output of the control transformer will be maximum.

Control Transformers (Continued)



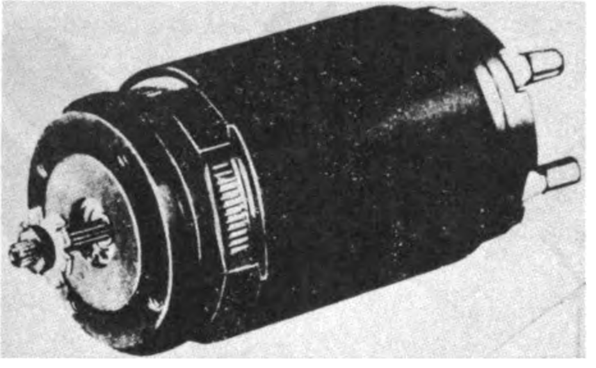
21. Typical Control Transformer, Disassembled



22. Typical Control Transformer, Phantom View

Control Transformers (Continued)

Accuracy in a synchro system is largely dependent upon the number and type of units used in the system. To increase accuracy and to save space, some control transformers have rotatable stators. The units provide the correction which would otherwise be made by the insertion of a synchro differential in the system.



23. Control Transformer with Rotatable Stator

When a control transformer with a rotatable stator is used in a data transmission system, there is no need for a synchro differential between the control transmitter and the control transformer. By eliminating the synchro differential unit from the system, whatever portion of receiver error that would have been contributed by the unit is also eliminated. Therefore, the synchro system that employs a control transformer with a rotatable stator usually provides a more accurate output than the system that employs the combination of a control transformer and a synchro differential.

Receiver error is the difference between the position transmitted and the position assumed by the receiver. This error is expressed in minutes of arc; thus, it is small.

The total receiver error for a synchro system that has a transmitter, a differential, and a receiver is the sum of the receiver error from the differential unit and the receiver error from the receiver unit. Eliminating the synchro differential unit from a system, therefore, reduces the total receiver error of that system.

UNIT CONSTRUCTION OF SYNCHROS

Summary

The two main components of any synchro are the rotor and the stator. Either winding can be the primary winding, but usually the rotor is the primary winding.

There are two main types of rotors: salient pole and drum wound. Salient-pole rotors have only a single winding; drum-wound rotors have either a single winding or three Y-connected windings, depending upon the unit using the rotor.

Differential units always use Y-connected windings on the rotor.

The stator has three windings, Y-connected and mounted 120° apart, and wound on the inside of the cylindrical frame of the synchro. Either the stator or the drum-wound rotor of a synchro may have skewed lamination slots.

Synchro transmitters and synchro receivers have almost the same physical and electrical construction. The major difference between a synchro transmitter and a synchro receiver is that a receiver generally has some type of mechanical or electrical damping to curtail excessive oscillations or spinning.

Synchro differential transmitters and receivers are different from synchro torque transmitters and receivers in that differential rotors have three Y-connected windings, while torque rotors have only one winding.

Synchro control transformers appear to be the same physically as synchro transmitters and receivers but differ in that a control transformer does not have a rotor damping device as does a receiver, and its rotor is drum-wound while transmitters and receivers have salient-pole-wound rotors. They differ electrically in that the rotor supplies a voltage output rather than a mechanical output.

When a synchro control transformer with rotatable stator is used, it is not necessary to have a synchro differential between the control transmitter and the control transformer. Each application for which a system is designed will reveal which type of electrical hookup is required.

Summary (Continued)

Receiver error is the difference between the position transmitted and the position assumed by the receiver. This error is expressed in minutes of arc.

The total receiver error for a synchro system that has a transmitter, a differential, and a receiver is the sum of the receiver error from the differential unit and the receiver error from the receiver unit. Eliminating the synchro differential unit from a system, therefore, reduces the total receiver error of that system.

STUDENT NOTES

TOPIC 4: CHARACTERISTICS OF SYNCHROS

You Are Now Going to Learn:

1. Definitions of the following terms:

   a. Torque.
   b. Electrical error.
   c. Receiver error.
   d. Synchronizing time.

2. Effects of the following characteristics:

   a. Operating voltages.
   b. Operating temperature.
   c. Operating speed.
   d. Minimum voltage.
   e. Fundamental component voltages.

Discussion Points for This Topic Are:

1. Rotor position.
2. Electrical zero.
3. Positive rotation.
4. Increasing input.
5. Angular position.

ASSIGNMENT:

OP 1303 (First Revision), pages 20-24.

PURPOSE:

To gain an understanding of the standard terms which describe synchro operation.

TOPIC 4: CHARACTERISTICS OF SYNCHROS

Torque

Torque is a force, or combination of forces, which produces a twisting motion. Synchro torque measurements are in ounce-inches. The torque developed by an electromechanical device is directly proportional to flux density and rotor current and inversely proportional to the impedance of the stator windings.

Torque gradient is measured in ounce-inches per degree and is usually included in design specifications of a synchro.

Torque gradient is the best measurement of the accuracy of a synchro system. If torque gradient declines, accuracy will decline. Torque gradient goes down when more receivers are added to the system, when the mechanical load on the receiver units is increased, or when the operating temperature goes up.

Therefore, the load capacity of a synchro transmitter is limited by the number and type of receiver units loading the transmitter, the loads on these receiver units, and the ambient operating temperature.

Operating Voltages

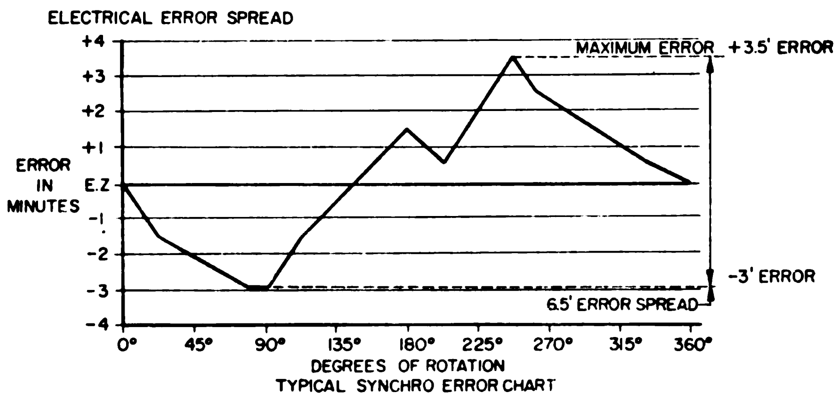
Shipboard synchros are usually designed for 115-volt operation at 60 cps. Aircraft units are usually designed for 26-volt operation at 400 cps. The nameplates on synchros have their operating voltage and frequency stamped on them. The operating voltage should never be exceeded.

Operating Temperature

Standard synchros are designed to withstand ambient temperatures ranging from - 67° to +170° F. More heat is generated by a synchro that is energized and loaded than by a synchro that is energized but not loaded. Similarly, overloading causes a synchro to generate much more heat than it would under normal loading conditions.

Electrical Error

Electrical error is defined as the difference between the electrical position and the physical position. Some amount of electrical error is inherent in any synchro because of eccentricities in design and manufacture. This error should remain constant; therefore, it is measured by the manufacturer. The figure given by the manufacturer is usually expressed in minutes of arc and represents the maximum electrical error.



24. Maximum Error and Spread Graph

Factors contributing to errors in synchros are burrs on the rotor shaft or the stator core, variation in mechanical roundness of the rotor shaft, and mismatching impedances of the three stator windings.

Receiver Error

Receiver error is defined as the difference between the actual rotor position of a synchro receiver and the position where it should be as commanded by a synchro transmitter. This error also is expressed in minutes of arc.

CHARACTERISTICS OF SYNCHROS

Synchronizing Time

Synchronizing time is the amount of time between the instant a receiver rotor begins to answer the command from a transmitter and the instant the receiver rotor comes to rest in agreement with the command position. This measurement is often made by moving the receiver rotor a definite interval away from a predetermined synchronization point and measuring the time required for the receiver rotor to come to rest at the transmitted synchronizing point.

Operating Speed

Synchros manufactured under specifications set up by the Bureau of Weapons must be capable of continuous operation for 1500 hours at 1200 RPM without load.

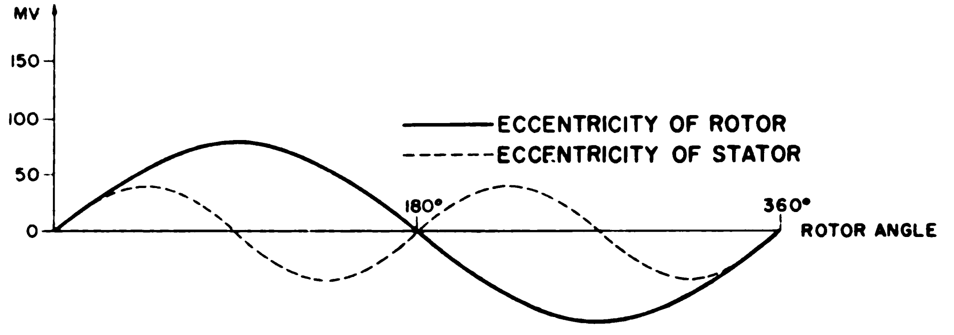
Prestandard synchros have two specifications, depending upon their use in a data transmission system. Low-speed synchros must be capable of continuous operation for 500 hours at 300 RPM without load, and high-speed synchros must be capable of continuous operation for 1500 hours at 1200 RPM without load.

Minimum Voltage and Fundamental Component Voltages

Minimum or null voltage is the S1-S3 output voltage at the "electrical zero" position of a synchro. A perfectly designed synchro should have no S1-S3 voltage output at the electrical zero position, but, up to the present time, manufacturing and design limitations have not made it possible to reach this perfection. Therefore, a minimum or null voltage is present at electrical zero and is composed of fundamental component voltages and certain harmonic voltages.

Minimum Voltage and Fundamental Component Voltages (Continued)

Fundamental component voltages are caused by manufacturing limitations and comprise 60% to 70% of the total null voltage. Two of these limitations are the amount a rotor rotates off center inside the stator and the deviation from the roundness of the stator itself. This voltage varies as the rotor is turned through an angle of 360° and is a combination of a one-cycle error and a two-cycle error.



25. Fundamental Component of Minimum Voltage

The voltage cycle may not start at the 0° rotor angle, but may begin anywhere through the 360° circumference of the synchro.

Harmonic voltage contributing to the null voltage is of a high frequency and is caused by the laminations and the skewed slots of either the rotor or the stator. Careful design of modern synchros has reduced this voltage until it is almost nonexistent.

Null voltages are not too important in a torque-type system. In a control-type system that is controlling a sensitive servo system, null voltage is of great importance. The electrical output from the stator of a control-type synchro that is controlling a servomotor must have a very low null voltage so that the servo will stop driving when the synchro is at its null position.

CHARACTERISTICS OF SYNCHROS

Standard Definitions

Angular position of a synchro: the amount of counterclockwise rotation by the rotor, viewed from the emergent shaft end and measured from electrical zero.

Electrical zero: the standard position at which the least amount of voltage is read between the S1 and S3 windings of a synchro transmitter or a synchro receiver. Coarse electrical zero is indicated on all standard synchros by an arrow etched on the case of the synchro and a line marked on the rotor shaft.

Rotor position: the angular position measured from electrical zero.

Standard positive rotation: counterclockwise rotation from electrical zero.

Torque: a force or combination of forces which produces a twisting motion.

Summary

The number and the type of synchro receivers, the mechanical loads on these receiver units, and the operating temperatures of both the transmitter and the receivers determine the load capacity of the synchro torque transmitter.

Operating voltages of standard synchro units are either 26 volts or 115 volts.

The ambient temperature at which these units operate ranges from -67° to +185° F.

Electrical error is the difference between the electrical position and the actual position. It is measured by the manufacturer and is expressed in minutes of arc.

Summary (Continued)

Receiver error is the difference between the transmitted position and the actual receiver position; it is measured in minutes of arc.

Synchronizing time is the amount of time a receiver takes to pass through a definite angular displacement and align itself with a transmitted synchronizing point.

Prestandard low speed units are capable of operating at 300 RPM for 500 hours, while prestandard high speed units can operate at 1200 RPM for 1500 hours.

Minimum voltage is the voltage present on the secondary winding when a synchro is at the electrical zero or null position. Fundamental component voltages comprise 60% to 70% of the minimum voltage. Second and third harmonic voltages make up the balance of the total minimum voltage.

SECTION 2

SYNCHROS IN ACTION

Topic No.	Topic Title	Page
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2	Torque Synchro Systems Containing Differential Units	60
3	Control Synchro System	72
4	Military Synchro Types	80
5	Hardware, Tools, and Synchro-Mounting Methods	86
6	Zeroing Synchros	104
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TOPIC 1: TORQUE TRANSMITTER AND TORQUE RECEIVER IN A SIMPLE SYNCHRO SYSTEM

You Are Now Going to Learn:

1. Uses of synchro systems.
2. Functional operation of components.
3. Operation of a simple synchro system.
4. Electrical alignment.
5. Application of the simple synchro system to Naval equipment.

Discussion Points for This Topic Are:

1. Torque.
2. Excitation.
3. Bearing friction.
4. Dial load.
5. Static inertia.
6. Reference points.

ASSIGNMENT:

OP 1303 (First Revision), pages 28-35 and 43-44.

PURPOSE:

To apply knowledge of unit operation toward the understanding of system operation.

TOPIC 1. TORQUE TRANSMITTER AND TORQUE RECEIVER IN A SIMPLE SYNCHRO SYSTEM

Uses of Synchro Systems

Just as synchros themselves can be classified as either torque-type or control-type, synchro systems can be classified according to use in the same way: torque-type or control-type. The type of synchro system used depends upon the specific purpose for which the system was designed: torque synchros for small torque requirements, control synchros for large torque requirements.

A torque-type synchro system is made up of one torque transmitter and one or more torque receivers. Although there is very little torque (measured in oz-in) developed in a torque synchro system as compared to the torque (measured in lb-ft) developed by some other motors of equivalent size, the torque of this type synchro system is sufficient for:

1. positioning dials and pointers,
2. opening and closing small electrical contacts, and
3. positioning small hydraulic valves.

Functional Operation of the Units in a Simple Synchro System

One synchro transmitter and one synchro receiver make up a simple synchro system. Basically, the electrical construction of synchro transmitters and receivers is similar; however, their intended functions are different.

The rotor of a synchro transmitter is usually geared to a mechanical input. This gearing may drive a visual indicator showing the value or quantity being transmitted.

TORQUE TRANSMITTER AND TORQUE RECEIVER IN A SIMPLE SYNCHRO SYSTEM

Functional Operation of the Units in a Simple Synchro System (Continued)

The rotor of a synchro receiver synchronizes itself electrically with the position of the rotor of a synchro transmitter. This synchronization takes place only when both units are energized from the same AC excitation and when the interconnections to the stator windings are correct.

As single units, synchro transmitters and synchro receivers are small and mechanically simple. When combined in a data transmission system, the combinations of units become dynamically complex but retain a high degree of stability and static transmission accuracy.

The factors limiting the overall accuracy of any synchro system are bearing friction and dial load. The minimum output torque of all units combined must be sufficient to overcome both the friction in the receiver bearings and the static inertia of the dial mounted on the receiver rotor.

Operation of a Simple Synchro System

Synchro systems are self-balancing or self-synchronizing systems. When the synchros of a synchro system are properly connected and have correct excitation, the rotors of the synchros will be in correspondence with each other. This means that the position of one rotor will be in electrical agreement with the position of any other rotor. This electrical agreement may occur at any point within the 360° arc of rotation.

When a synchro receiver is in correspondence with a synchro transmitter, there is no current flow in the stator windings of the synchro transmitter; hence, no magnetic field is established around the stator windings of the synchro receiver; hence, no magnetic force is exerted on the rotor of the synchro receiver. At this one point, the point of correspondence, the current flow in the circuit is effectively zero. This is true because the induced voltages in the windings of the two stators are equal and constant.

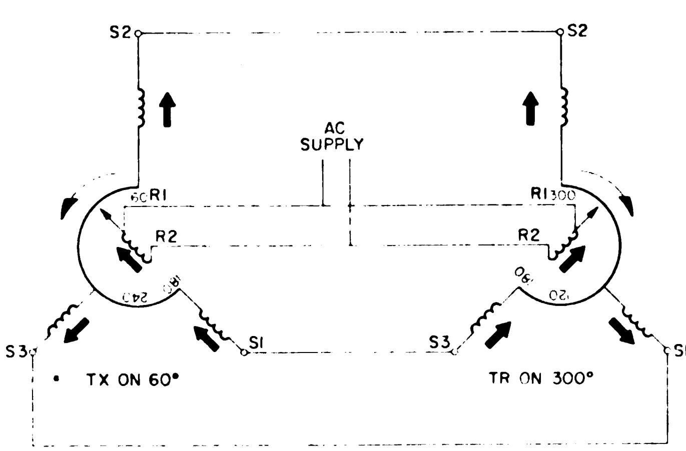
TORQUE TRANSMITTER AND TORQUE RECEIVER IN A SIMPLE SYNCHRO SYSTEM

Operation of a Simple Synchro System (Continued)

A voltage change induced into the transmitter stator by the sudden movement of the rotor will cause the balanced voltages between the transmitter and receiver stators to be disrupted instantaneously. This unbalanced condition causes current to flow through the stator windings in both the transmitter and receiver, causing the rotor of the receiver to rotate toward synchronization with the transmitter rotor. When synchronization has been achieved, current flow stops; the magnetic fields around the stator windings collapse; and the voltages induced into the stator windings of the synchro transmitter and receiver are again equal. The continual sequence of these events causes the synchros in the system to stay in correspondence.

Actually, the two rotors are never very far out of correspondence with each other. The instant the transmitter rotor starts to rotate, current flows in the stator windings, immediately causing the receiver rotor to follow the transmitter rotor. The lag between the synchro transmitter and receiver is governed by the amount of both bearing friction and electrical error in the receiver.

There is nothing unusual about the electrical connections made to reverse the rotation of the rotor of a synchro receiver in relation to rotor rotation of a synchro transmitter. The synchro transmitter S1 and S3 leads are simply reversed at the synchro receiver. S1 and S3 are the only leads ever reversed in standard synchro connections.

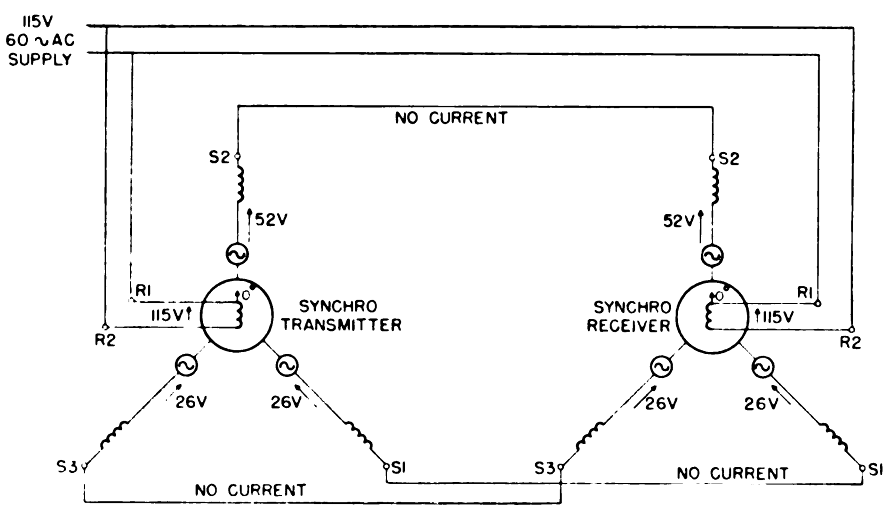


26. Reverse Rotation of a Synchro Receiver

Operation of a Simple Synchro System (Continued)

The slightest movement of the transmitter rotor unbalances the induced voltage in the stator. The amount of voltage unbalance between the stator of the synchro transmitter and the stator of the synchro receiver depends upon the relative position of the rotors of the two units. In actual practice, a synchro system has very little current flow in the stators of the units because the receiver rotor immediately moves in a direction to balance the induced voltage from its stator with the transmitter stator voltage. High current flow exists when the synchro system is initially energized, when there are sudden or rapid movements of the transmitter rotor, and when the receiver load is too great.

The currents in the three stator windings are always 120° out-of-phase with each other. The maximum current flow in any one stator winding occurs when the rotors of the synchro transmitter and receiver are 90° apart with the synchro receiver rotor positioned to induce maximum voltage in one particular winding.

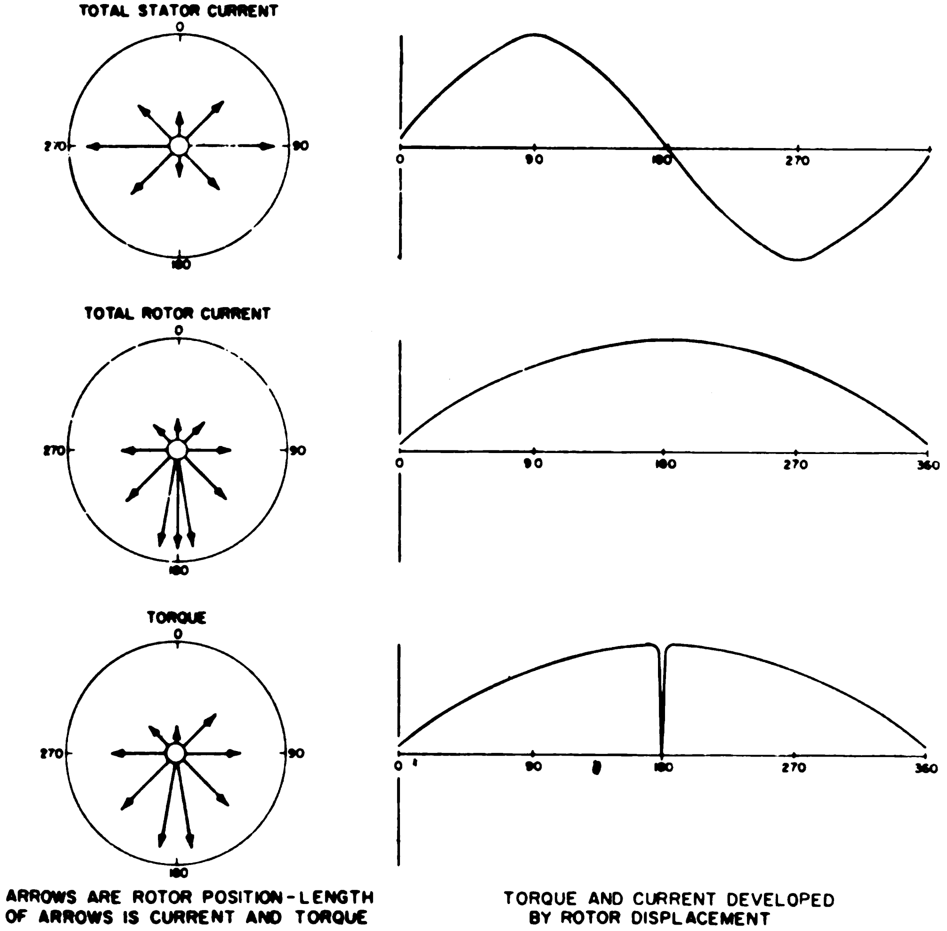


27. Maximum Induced Voltage in Receiver

TORQUE TRANSMITTER AND TORQUE RECEIVER IN A SIMPLE SYNCHRO SYSTEM

Operation of a Simple Synchro System (Continued)

Since a synchro and a transformer have similar electrical characteristics, it should be obvious that very little current will flow in the rotor (or primary winding) of a synchro when there is no load on the stator (or secondary winding). With a load, however, current flow in the rotor will increase in direct proportion to the displacement of the rotor from the stator; maximum current will flow when the two are displaced 90°. Thus, minimum current will flow not only at the 0° displacement position but also at the 180° displacement position. This should seem natural since, for both cases, the reason is the same: the currents in the two opposing stator windings (S1 and S3) are of equal magnitude but of opposite phase.



28. Stator and Rotor Current and Torque Relationship

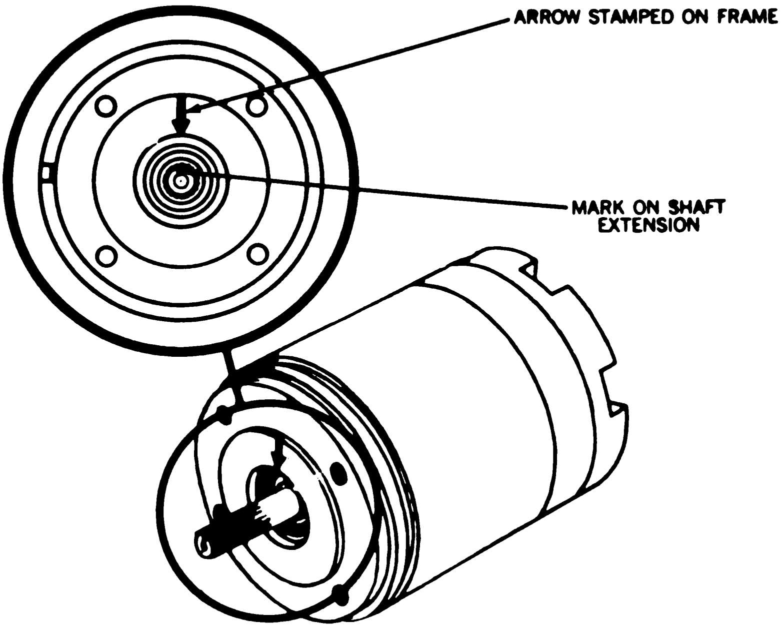
TORQUE TRANSMITTER AND TORQUE RECEIVER IN A SIMPLE SYNCHRO SYSTEM

Operation of a Simple Synchro System (Continued)

From 0° to 179° 59' rotation and from 180° 01' to 0° rotation, torque is directly proportional to the current flow in the rotors of the synchro transmitter and receiver. At exactly 180° displacement, torque drops sharply to minimum. Minimum torque exists at 180° displacement because of the equal and opposite forces exerted by the current flow in the stator windings of both the synchro transmitter and receiver. Torque rises sharply to the maximum at the slightest movement of the synchro receiver rotor either way from the 180° displacement position of the synchro transmitter rotor.

Electrical Alignment

Every standard synchro unit manufactured for use in Navy installations has coarse electrical-zero markings on the synchro frame and the shaft extension. Prestandard synchros have no markings. After the coarse electrical-zero markings have been aligned on each synchro, each transmitter and receiver must be aligned to fine electrical zero. Fine electrical zero is the reference point for alignment of all synchros. For a synchro transmitter or receiver, this reference point is the rotor position at which the lowest open-circuit voltage is read on stator terminals S1 and S3.



29. Coarse Electrical Zero Markings

TORQUE TRANSMITTER AND TORQUE RECEIVER IN A SIMPLE SYNCHRO SYSTEM

Electrical Alignment (Continued)

Electrical zero, as a reference point, is vital in the maintenance and servicing of synchros. Without electrical zero, synchro systems would be useless because there would be no way of assuring correct correspondence. No maintenance or servicing of synchros should be attempted without first aligning the synchro to electrical zero.

There is another reference point that must be considered when aligning any synchro system. It is the mechanical reference point. This point is relative to the needs, design, and use of each synchro system. For example: ships course indicators are referenced to true north; relative bearing indicators are referenced to the bow of the ship; range indicators are referenced to ten thousand yards.

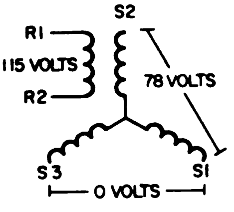
System alignment in any data transmission system is always done as follows:

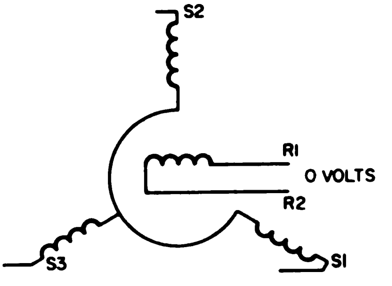
1. Position the synchro receivers to the mechanical reference.
2. Align the synchro receivers to electrical zero.
3. Position the synchro transmitter to the mechanical reference.
4. Align the synchro transmitter to electrical zero.

Methods of zeroing synchros are discussed in detail in Topic 6 of this section.

Electrical Alignment (Continued)

In fire control equipment such as a director and gun mount, the mechanical transmitting element, the director, and the mechanical receiving element, the gun, are set on zero before the synchros are checked for misalignment. In the case of the after guns, a mechanical angle of 180° is used.





30. Terminal Voltages

Terminal voltages for synchro torque transmitters, torque receivers, or control transmitters are shown in the accompanying figure. Complete zeroing procedures for all types and classifications of synchros are given in OP 1303 (First Revision), pages 75-81.

The overall accuracy of a simple synchro system depends upon the units used in the system, the load on the receiver, and the man doing the alignment.

TORQUE TRANSMITTER AND TORQUE RECEIVER IN A SIMPLE SYNCHRO SYSTEM

Application of the Simple Synchro System to Naval Equipment

A pitometer log is an instrument which performs the same function for a ship as the speedometer and odometer do for a car; that is, it measures speed and mileage. A car uses flexible shaft transmission from the gear box to the speedometer and odometer. A pitometer log uses synchro system transmission from the pitometer sword in the bottom of the ship to the bridge, engine room, Combat Information Center (CIC), plotting room, and sonar room.

From the mast yardarm, wind direction and speed are transmitted by synchro to instruments on the bridge and in CIC. Synchro systems are also used to indicate propeller-shaft revolutions, rudder order, and engine order at various locations throughout the ship.

Values of own ships course are derived from the ships master gyrocompass and are remotely indicated by torque synchro systems. To eliminate any possible drag on the master gyrocompass, a synchro amplifier is used to amplify the output of the torque transmitter. Amplifying the transmitter output before it is sent to the torque receiver allows minimum loading of the torque transmitter and, therefore, minimum drag or loading of the master gyrocompass.

More synchros are used in fire control equipment than in any other type of naval equipment. Radar systems, surface or air, search or directional, also use many synchro systems to transmit values of range, azimuth, and elevation to combat and navigation stations throughout the ship.

The Navy has recently advanced from the firing of just projectiles to the launching of self-propelled missiles. Although new missile fire-control systems are much more complex than conventional gun fire-control systems, synchros and the various synchro systems have not been excluded from new system designs. Instead, modern technology has proved that the standard type of synchro is very adaptable to the demands of this missile age. Synchros have been miniaturized physically while remaining unchanged electrically; thus, they can be smaller and lighter while performing the same conventional functions.

TORQUE TRANSMITTER AND TORQUE RECEIVER IN A SIMPLE SYNCHRO SYSTEM

Summary

Torque-type synchro systems are used for positioning small mechanical loads without benefit of any power-amplifying devices.

Synchro systems are self-balancing systems. With proper electrical connections and correct excitation voltage, synchro transmitter and receiver rotors will stay in correspondence with each other.

Reversing the S1 and S3 connections in any synchro receiver reverses the rotation of that receiver.

No torque exists on the rotor of a synchro receiver when it is exactly in correspondence to or 180° displaced from the rotor of a synchro transmitter.

Electrical zero is the reference point for electrically aligning a synchro. The mechanical reference point is the reference for physically positioning a synchro. The electrical zero and the mechanical reference points must be in alignment before any particular system can be considered aligned.

Most weapon systems used by today's Navy contain synchros.

STUDENT NOTES

TOPIC 2: TORQUE SYNCHRO SYSTEMS CONTAINING DIFFERENTIAL UNITS

You Are Now Going to Learn:

1. Purpose of a differential unit.
2. Functional operation of a torque differential transmitter.
3. Functional operation of a torque differential receiver.
4. Rules for connecting differential units.
5. Use of synchro capacitors.

Discussion Points for This Topic Are:

1. Subtraction with a torque differential unit.
2. Addition with a torque differential unit.
3. Connection for the sign of rotation.
4. Definition of standard synchro connections.

ASSIGNMENT:

OP 1303 (First Revision), pages 25-26, 35-44, and 78-80.

PURPOSE:

To learn the purpose and function of torque differential units.

TOPIC 2. TORQUE SYNCHRO SYSTEMS CONTAINING DIFFERENTIAL UNITS

Torque Differential Units

There are two types of differential units: differential transmitters and differential receivers. A differential transmitter accepts one electrical input and one mechanical input and produces one electrical output. A differential receiver accepts two electrical inputs and produces one mechanical output.

A torque differential transmitter (TDX) provides an electrical output from its rotor to the stator of a torque receiver (TR) or a torque differential receiver (TDR). This electrical output of the TDX may be either the sum or difference of two inputs: an electrical input from a torque transmitter (TX) and a mechanical input from, perhaps, a handcrank. Whether the output represents the sum or the difference of the two inputs depends upon how the three units, the TX, the TDX, and the TR, are connected.

A TDR provides a mechanical output from its shaft. This mechanical output may be either the sum or difference of electrical inputs to both the rotor and stator from two different torque transmitters or torque differential transmitters. Again, the addition or subtraction function depends upon how the units are connected.

The interaction between the magnetic fields around the three stator windings of both the torque transmitter and the torque differential transmitter is quite complex; however, the result of the combined fields is rather simple.

The voltage output from the stator of the torque transmitter provides the input to the three Y-connected windings of the torque differential transmitter stator. By transformer action, this input voltage is induced into the three Y-connected rotor windings of the TDX. The TDX rotor voltage is sent to the stator of the torque receiver, affecting the position of the TR rotor. From this instantaneous sequence of events, the TR rotor is made to follow any rotation of the TX or TDX rotor.

TORQUE SYNCHRO SYSTEMS CONTAINING DIFFERENTIAL UNITS

Torque Differential Units (Continued)

Torque synchro systems containing differential units are discussed in OP 1303 (First Revision), pages 35-44. Since the discussion in OP 1303 is based upon the interaction between magnetic fields when a system is unbalanced, the following discussion will be based upon rotation and will be only an addendum to the discussion in the OP.

It has been sufficient up to this point to say that the method of interconnecting a TR or TX and a TDX determines whether the differential output is the sum or the difference of its two inputs. Now, however, one should become aware of exactly how to arrange the circuitry to get either the sum or the difference output.

The term standard synchro connections is defined as the connection arrangement which allows an increasing value of output from one unit to produce an increasing value of input to a second unit. This may be stated in other terms by saying that counterclockwise rotor rotation of one unit will produce counterclockwise rotor movement of a second unit.

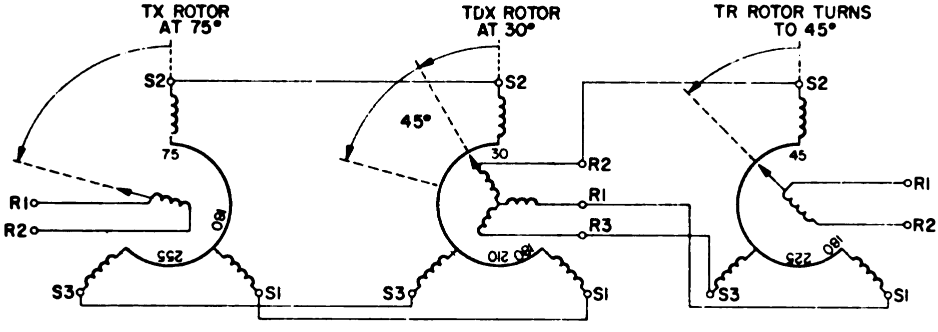
Nonstandard synchro connections deviate from the standard arrangement only in that stator leads S1 and S3 are reversed on one of two units. Stator lead S2 is connected to another S2 stator terminal for either the standard or nonstandard arrangement.

The fact that both the TX rotor and the TDX rotor are held is important and should be kept in mind. Being held means that the rotors are physically held in position and that movement of one rotor does not produce movement of the other. The second rotor would like to move so that it could align itself with the new field, but it cannot because it is physically held in its original position.

TORQUE SYNCHRO SYSTEMS CONTAINING
DIFFERENTIAL UNITS

Torque Differential Units (Continued)

The fact that the TR rotor is always free to rotate should also be kept in mind. The output from the illustrated system is a torque taken from the shaft of the TR rotor; therefore, it must be free to rotate at all times.



31. Torque Synchro System with TDX Connected for Subtraction

The accompanying figure illustrates an example of a torque differential transmitter producing the difference between its two inputs. Note that the synchro connections are standard and that rotor position is referenced to the 0° position when the rotor is aligned with stator winding S2.

The illustrated problem began with all rotors at their 0° positions. The TX rotor was rotated 75° counterclockwise; thus, the first input was 75° and positive. The TDX rotor would have liked to follow the movement of the TX rotor, but it was physically held in place. This caused a 75° unbalance between the fields of the TDX rotor and stator.

The second input to the system was inserted by manually driving the TDX rotor 30° counterclockwise; thus, the second input was 30° and positive.

Torque Differential Units (Continued)

By rotating the TDX rotor in the positive direction, the amount of unbalance between the TDX rotor and stator was reduced. Since the amount of unbalance is the amount of input to the TR, the TR rotor moved to indicate the difference between the two inputs.

A general mathematical expression that would be true in all cases may be stated as follows:

TX input - TDX input = TR output

For the illustrated problem, the values are:

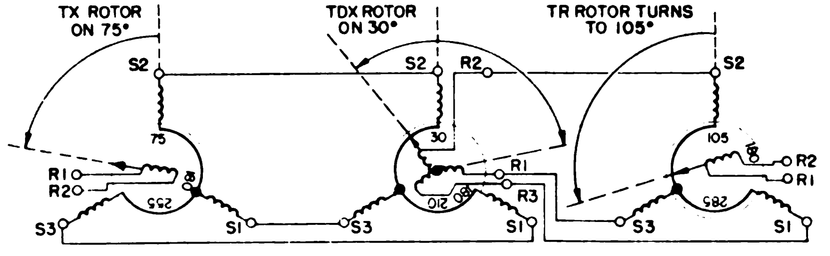
$$(+75°) - (+30°) = +45°$$

A torque differential transmitter produces the sum of two outputs when the synchro connections are nonstandard. In the figure illustrating the connections for addition, note that TX stator lead S3 is connected to TDX stator lead S1, and that TDX rotor lead R3 is connected to TR stator lead S1. These connections are termed "reverse" or "nonstandard."

It is important to realize that, because of the reversed synchro connections, reverse rotation results. Counterclockwise rotation of the TX rotor causes a positive unbalance between the fields of the TDX rotor and stator. If the TDX rotor were free to move, it would indicate the positive input but would rotate in a clockwise direction. Since the TDX rotor cannot move, it transmits its unbalance to the stator of the TR, causing the TR rotor to indicate a positive input by rotating counterclockwise.

Torque Differential Units (Continued)

To reduce the action to the simplest terms: when the connection arrangement is reversed, rotation is reversed from unit to unit. Another expression of the same idea is that, with nonstandard connections, every other unit rotates in the same direction.



32. Torque Synchro System with TDX Connected for Addition

The illustrated problem of addition began with all rotors at their 0° positions. The TX rotor was rotated 75° counterclockwise; thus, the first input was 75° and positive. The TDX rotor would have liked to follow the movement of the TX rotor, but it was physically held in place. This caused a 75° unbalance between the fields of the TDX rotor and stator.

The second input to the system was inserted by manually driving the TDX rotor 30° counterclockwise; thus, the second input was 30° and negative. The negative sign comes from the reverse rotation. If counterclockwise rotation of the TX rotor is considered positive, clockwise rotation of the TDX must be considered positive due to the fact that the two units are connected for reverse rotation.

The amount of unbalance between the fields of the TDX rotor and stator was 0° at the very beginning of the problem, was increased to 75° by the first input, and was increased another 30° by the second input. Thus, the total unbalance became 75° +30° or 105°.

Torque Differential Units (Continued)

The same mathematical expression may be used to determine the TR output.

TX input - TDX input = TR output

For the illustrated problem, the values are:

$$(+75°) - (-30°) = +105°$$

Since the same equation describes the result of adding or subtracting and since the answer is not the same for both processes, it follows that the two situations must differ in some way. The difference is rotation. The direction of rotation determines whether the amount of rotation should be termed positive or negative. The following table lists the standard convention for determining whether rotation is positive or negative.

Table 1. Standard Convention for Sign of Rotation

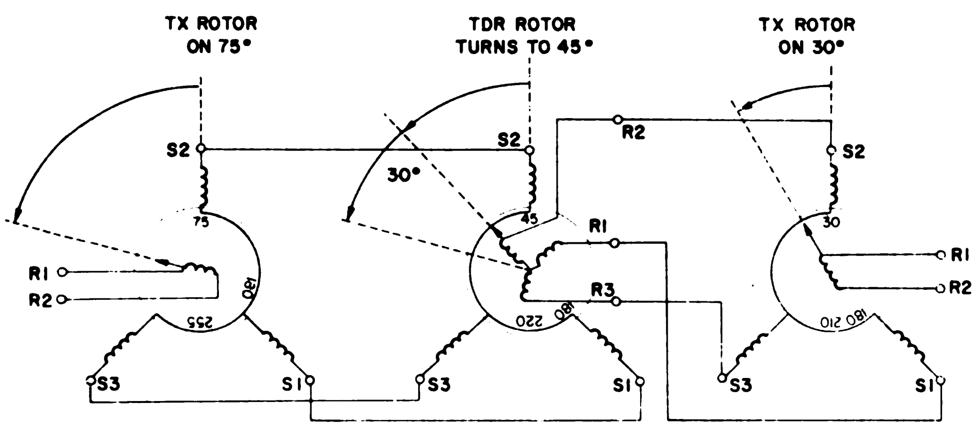
Clockwise Rotation	Synchro Connections	Counterclockwise Rotation
-	Standard	+
+	Nonstandard	-

The function of a synchro differential receiver is similar to, but not the same as, that of a differential transmitter. The electrical functions of the two units are the same; however, the physical applications and, therefore, the physical functions of the two units are dissimilar.

Torque Differential Units (Continued)

Torque differential receivers (TDR) are driven by the outputs of two torque transmitters; thus, both TDR inputs are electrical. The TDR output is a torque generated by movement of the TDR rotor shaft.

The figure below illustrates a torque synchro system containing two TX units and one TDR unit. In this type of system, the two TX rotors are physically held in place, and the TDR rotor is allowed to move freely.



33. Torque Synchro System with TDR Connected for Subtraction

In the illustrated problem, the first input was of 75° in the counterclockwise direction; thus, the first input was a positive 75°. The second input was of 30° in the counterclockwise direction; therefore, it was a positive 30°.

The unbalance between the two inputs was the amount of TDR rotor movement.

Torque Differential Units (Continued)

For the purpose of discussion, the action may be slowed to a step-by-step sequence. Beginning with all rotors positioned at their 0° reference points, an input of +75° was inserted into the system by manually positioning the rotor of the TX which is illustrated on the left. The TDR rotor answered by rotating 75° in the counterclockwise direction. Keep in mind that since the second TX, illustrated on the right, had not yet offered an input, its rotor was still at its initial 0° reference position.

To summarize the action thus far, the first TX rotor moved to 75°, the second TX rotor stayed at 0°, and the TDR rotor moved to 75°.

The second input of +30° was then inserted into the system by manually positioning the rotor of the second TX 30° in the counterclockwise direction. Thus, the relative difference between the two TX rotors was 75° - 30° = 45°. The TDR rotor, in order to indicate the difference, rotated 30° in the clockwise direction to indicate 45°.

Standard synchro connections between the two TX's and the TDR allow the difference between the two TX inputs to appear as a torque output on the rotor shaft of the TDR. It follows that, if the synchro connections at the two TX's are made nonstandard, the TDR output will be the sum instead of the difference.

Synchro Capacitors

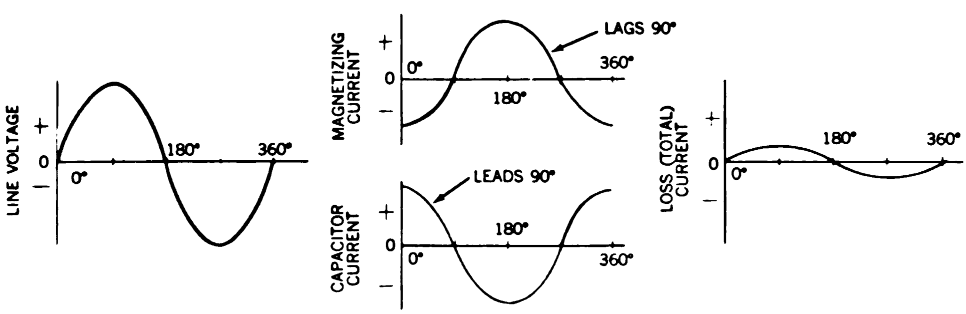
In an AC circuit, current in a coil lags the applied voltage by an amount proportional to the impedance of the coil. The amount of lag can be as much as 90°.

Synchro Capacitors (Continued)

In a circuit where a transmitter is supplying a signal to a differential unit or control transformer, the transmitter is supplying a lagging current to the stator of the differential unit or control transformer. To minimize the amount of current lag and, thereby, improve the accuracy of the system, a capacitive network is placed in the circuit.

In an AC circuit, current in a capacitor leads the applied voltage by an amount proportional to the impedance of the capacitor. The amount of lead can be as much as 90°.

Current in the coiled stator windings of a differential unit or control transmitter tends to lag the induced voltage by about 90°. Current in the capacitive network tends to lead the induced voltage by about 90°. Adding the capacitive network to the circuit would result in two currents opposing each other, adding to zero, and leaving very little current to be induced into the stator windings.

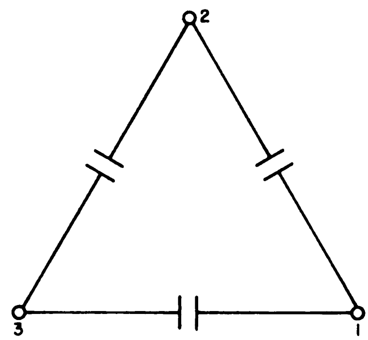


34. Line Current Loss in Stator of Synchro Receiver Using Delta-Wired Synchro Capacitors

Inserting the capacitive network in the circuit is, therefore, the key to the desired result. This network is generally termed a synchro capacitor, even though the network contains three individual capacitors and the total capacitance of all three capacitors is the rated value of the network.

Synchro Capacitors (Continued)

The three capacitors are usually delta-wired; that is, they form an electrical triangle. The adjacent plates of each pair are tied to a common point. The following illustration will help make this description more clear.



35. Delta-Wired Capacitors

To insert the capacitive network into the circuit, common points 1, 2, and 3 are connected to stator winding terminals S1, S2, and S3, respectively. The connections are generally as short as possible; high currents in long lead runs increase the transmitter load and reduce the system accuracy.

Synchro capacitors decrease the line current drawn by synchro systems and, in effect, increase the torque of the synchro receivers in the system. This effective increase in torque near the point of synchronization increases the accuracy of the overall system.

Torque or control synchro systems utilizing differential units are interconnected in various ways depending upon the final receiver output desired. The rules for these differential connections have already been explained and illustrated in this section.

Synchro systems containing differential units are zeroed in the same sequence as systems without synchro differentials. Synchro transmitters are always zeroed before differential transmitters.

TORQUE SYNCHRO SYSTEMS CONTAINING DIFFERENTIAL UNITS

Synchro Capacitors (Continued)

Electrical zero on differential units is marked in the same way as on conventional synchro units: an arrow is stamped on the case of the unit and a reference line marked on the emergent shaft. When these are aligned, the resultant position is coarse electrical zero for the unit. There are several methods of determining fine electrical zero for differential units noted in OP 1303 (First Revision), pages 78, 79, and 80. The most common method of zeroing synchros, however, is the voltmeter method.

Summary

A differential unit will provide either the sum of or the difference between its two inputs. The function of addition or subtraction is determined by the connection arrangement. With standard synchro connections, differential units subtract; with nonstandard connections, differential units add.

When the connections of a synchro are standard, counterclockwise movement of its rotor is considered positive. Conversely, when the connections of a synchro are nonstandard, counterclockwise movement of its rotor is considered negative.

Synchro differential transmitters and receivers differ only physically. The receiver has a damper; the transmitter does not. Schematic representation of either unit is the same: a three-winding, Y-wound rotor and stator.

To improve the accuracy of a synchro system, synchro capacitors are delta-wired in the stator circuits. These capacitors lower the line current and increase torque near the point of synchronization.

Coarse electrical zero is marked on differential units in the same manner as on other synchro units. The procedure used to zero a differential unit and to align synchro systems containing differential units is the same as that used to zero a conventional synchro.

TOPIC 3: CONTROL SYNCHRO SYSTEM

You Are Now Going to Learn:

1. Types of control synchro units.
2. Operation of a simple control synchro system.
3. Types of errors in control synchro systems.

Discussion Points for This Topic Are:

1. Control transmitter.
2. Control transformer.
3. Control differential transmitter.

ASSIGNMENT:

OP 1303 (First Revision), pages 44-48 and 80-81.

PURPOSE:

To learn the purpose and function of control synchro units and how these units operate in a simple control synchro system.

TOPIC 3. CONTROL SYNCHRO SYSTEM

Control Transmitters and Control Transformers

Control synchro systems are used in place of torque synchro systems when higher torque and more accuracy are required.

There are three functional types of control synchros used in any control synchro system. Two of these types, a control transmitter (CX) and a control transformer (CT), when used in conjunction with a servo amplifier and servomotor, make up a simple servo system.

The control transmitter is electrically and physically the same as the torque transmitter. Each transmitter performs the same function; each provides a voltage output from the stator. The magnitude and phase of this voltage output are dependent upon the amount and direction of rotor displacement from electrical zero. The electrical output of the CX is usually transmitted to a CT, which also produces an electrical output.

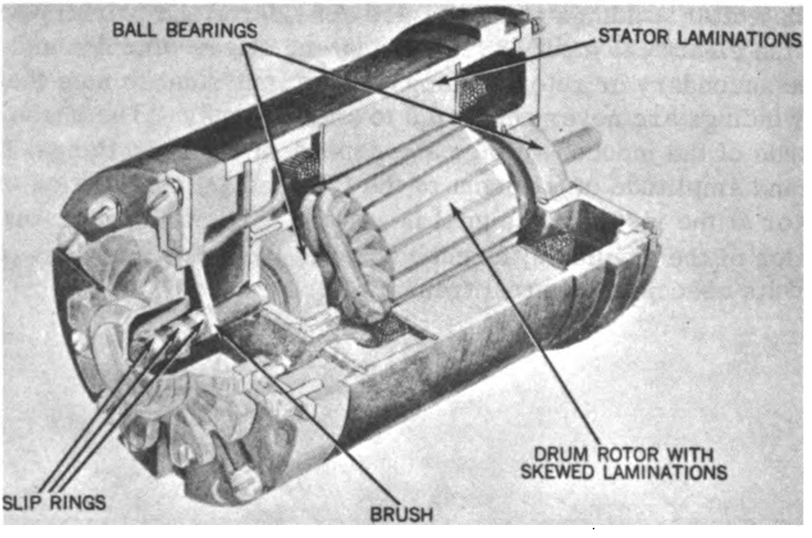
The stator windings of the CT are considered the primary windings. Thus, the electrical input is received on the stator windings and induced into the secondary or rotor windings. It is important to note that the CT rotor windings are never connected to an AC supply. The phase and amplitude of the induced voltage are dependent upon two things: (1) the phase and amplitude of the input to the CT, and (2) the position of the CT rotor at the instant the signal is applied. The CT voltage output is a function of the angular difference between the rotor positions of the CT and its associated control transmitter.

Control Transmitters and Control Transformers (Continued)

Control transformers have a single-phase distributed coil on a drum-wound rotor. Two sliprings on the emergent shaft and two brushes serve to conduct the voltage output to an amplifier.

The stacked laminations of the drum-wound rotor of the control transformer are skewed. The slots between the stacked laminations are slanted to prevent "slot lock". A cogging effect is produced by the interaction between the magnetic fields of the rotor and the stator when the slots between the stacked laminations are parallel to the rotor shaft centerline. Skewing the slots of either the rotor or stator of a synchro unit eliminates the possibility of "slot lock."

By eliminating the possibility of "slot lock", the output of the CT is more sensitive; that is, a very small input can produce a very small output. Electrical errors in the output of a control transformer have been decreased to ±2' of arc by the accurate skewing of the slots and by the proper distribution of the windings on the drum-wound rotor.



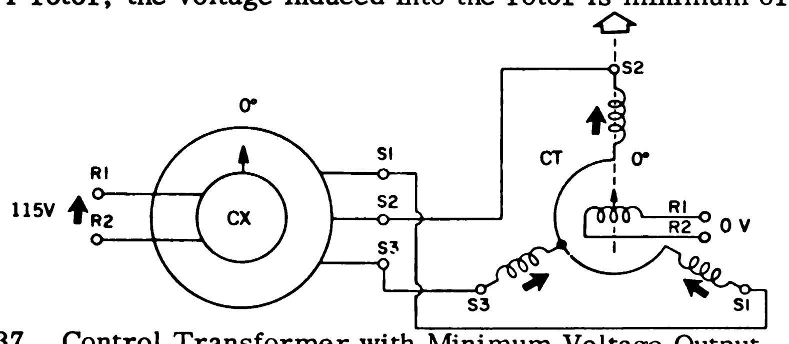
36. Drum-Wound Rotor, Cutaway View

Control Transmitters and Control Transformers (Continued)

The rotor and stator windings of a CT are usually of very high impedance, as much as three times the impedance value of a control transmitter or a control differential transmitter (CDX). Current flow in these high impedance windings is much less than in the windings of a CX or CDX. The largest CT draws about 40 milliamperes maximum in each of its stator windings, depending upon rotor position.

CT Stator Voltages

The CT receives an input voltage on its stator windings from the stator windings of a CX or a CDX. When the CX or the CDX is at its electrical zero position and when the rotor of the CT is at its electrical zero position, the resultant magnetic field of the CT stator induces minimum voltage in its rotor windings. In other words, when the resultant magnetic field of the CT stator is at right angles to the magnetic axis of the CT rotor, the voltage induced into the rotor is minimum or zero.

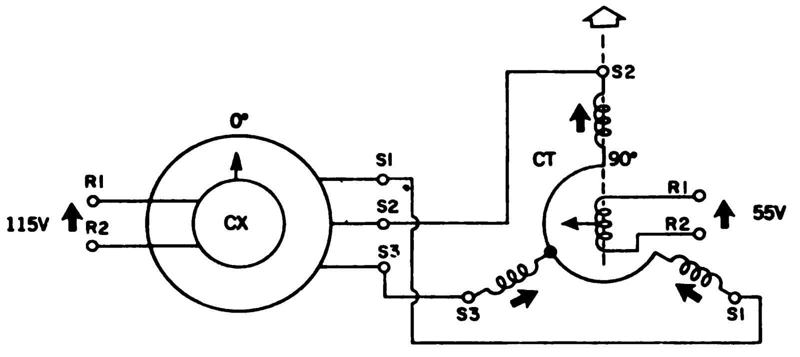


37. Control Transformer with Minimum Voltage Output

The behavior of a CT differs from that of most other synchro units. The rotor of a CT is wound in such a way that rotor position has a negligible effect upon the stator current. Also, no appreciable current.flows in the rotor of a CT because the output voltage from the rotor is always applied to a high impedance load. Thus, the magnetic field of the CT rotor does not try to follow the magnetic field of its stator.

CT Stator Voltages (Continued)

When the CX or CDX rotor is at its electrical zero position and the CT rotor is rotated 90° in either direction, a maximum of 55 volts is induced by the stator windings into the rotor windings. The phase of this maximum CT output depends upon the direction in which the CT rotor is moved.



38. Control Transformer with Maximum Voltage Output

When the amount of displacement between the CX and CT rotors is from 0° to 90°, the induced voltage on the CT rotor is proportional to the amount of displacement and is in phase with the excitation from the CX. When the displacement between the two rotors is from 0° to -90°, the induced voltage is still proportional to the amount of displacement but is 180° out-of-phase with the excitation from the CX.

CT Stator Voltages (Continued)

When electrically aligning units in a synchro control system, the CX should be the first unit aligned to its mechanical and electrical zero positions. This provides the reference for aligning the CT in the system to its electrical zero position.

In the normal operation of a simple control synchro system containing a control transmitter, control transformer, servo amplifier, and a servomotor, very little voltage appears at the rotor terminals of the CT because the response from a drive motor repositions the CT rotor into alignment with the CX rotor. The slightest movement of the CX rotor from an aligned position with the CT rotor causes a voltage to appear at the terminals of the CT rotor. This voltage is amplified and causes the drive motor to reposition the CT rotor to agree with the new position of the CX rotor. The absence of voltage output at this time causes the motor to stop driving, and the entire system comes to rest.

Capacitor requirements in a control synchro system depend upon the size of the units in the system. Capacitors used in these systems should be matched within 1% of each other, and total capacitance tolerance should be ±10%. The capacitors to be used with a specific system are chosen for their ability to nullify the unwanted magnetizing current flowing in the stator windings. Current flow in the capacitors of the system should be equal and of opposite phase to the current flow in the stators of the control transformer or differential unit in use in the system. Total current flow in the stator windings of a CT or CDX is decreased by as much as 75% by the use of the correct capacitance values.

Errors in control synchro systems are of two types: static and dynamic. Emphasis is usually placed on the static error, but dynamic error should also be considered. The output voltage from the rotor of the CT is a function of the displacement between that rotor and the rotor of the CX. The speed at which the CT rotates toward correspondence contributes an error voltage known as dynamic error. This speed error amounts to approximately 1° in a synchro rotated at the rate of 180° per minute; it is overcome in some control synchro systems by an opposing voltage from a small generator geared to the CT.

CT Stator Voltages (Continued)

When torque and control units are used in the same synchro system, errors in the system tend to increase. Torque receiver synchros are subject to receiver errors whereas control-type synchros are not. These receiver errors reflect back to the transmitter and, in effect, cause transmission error to the control-type synchros in use in the system. Modern manufacturing methods along with more rigid specifications have nearly eliminated receiver errors. At present, some companies are doing research on units with two windings on one rotor shaft. This type of synchro can be used either as a torque receiver or as a control transformer, using the specific rotor winding necessary for either primary excitation or secondary output voltage. In either case, the synchro transmitter must be of the torque type.

Naval examples of torque and control-type synchros in systems are too numerous to mention. Range indications from a PPI radar scope in CIC to an indicator on the bridge or in the plotting room is one of the simplest torque synchro systems. The rotary motion of a sonar transducer caused by manually turning a handcrank attached to the rotor of a control transmitter in the sonar room is a good example of a control-type synchro system.

Summary

Three functional types of synchros are used in control synchro systems. These are the control transmitter (CX), the control differential transmitter (CDX), and the control transformer (CT).

The relationship of CT stator voltage to rotor field is such that an amount of rotor displacement from 0° to 90° will cause a voltage output, proportional to the amount of displacement, from 0 to 55 volts. This output voltage will be in phase with the excitation voltage when the CT rotor is rotated counterclockwise and will be 180° out-of-phase when the CT rotor is rotated clockwise.

Summary (Continued)

The control transmitter should be set at mechanical and electrical zero. This setting then is used as a reference to find electrical zero or the position of null voltage of the CT in the control system.

Capacitor requirements are a design feature of the synchro system. The three delta-connected capacitors should be impedance matched to within 1% of each other; total capacitance should be within $\pm 10\%$ of the rated value.

There are two types of electrical errors in a control system: (1) static errors, which are caused by manufacturing methods and which vary with the angular position of the CT rotor; and (2) dynamic errors, which vary with the speed of rotation of the rotor of the CT.

Torque transmitters may be used in a control synchro system when accuracy is not of prime importance.

TOPIC 4: MILITARY SYNCHRO TYPES

You Are Now Going to Learn:

1. Military standards for synchros.
2. Standard designation code for synchros.
3. Prestandard designation code for synchros.

Discussion Points for This Topic Are:

1. Synchro nameplates.
2. Designation codes.

ASSIGNMENT:

OP 1303 (First Revision), pages 51-62.

PURPOSE:

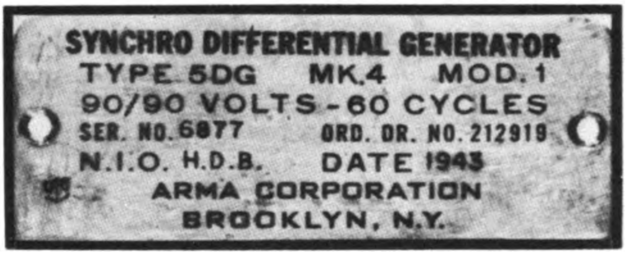
To learn to read and understand coded nomenclature on a synchro nameplate.

TOPIC 4. MILITARY SYNCHRO TYPES

Military Standards

Specifications for the manufacture of all synchros for use in the military services were set up by the Department of Defense in 1958. This was the first attempt to standardize specifications for synchros throughout the military services.

Before 1958, the individual services had issued specifications governing the manufacture and the physical and electrical characteristics of only certain sizes and types of synchros. The Navy has issued more specifications than the other services, possibly because more synchros are used in the Navy.



39. Prestandard Synchro Nameplate

Military Standards (Continued)

The military-standard type-designation code details the outside diameter, the function, and the operating frequency. These three specifications are usually imprinted on a decal or nameplate affixed to the frame of the synchro. Manufacturers usually include other data on the nameplate, such as the cognizant government agency (Army, Navy, DOD), the weight of the unit, and a drawing number.

40. Synchro with Military Standard Synchro Nameplate

Military Standards (Continued)

Specifications issued by BuOrd in 1949 standardized the size of and nomenclature for 400-cycle synchros used by the Navy. The Navy is gradually replacing all prestandard synchros with the latest standard-type synchros. New missile launcher, gun, and director installations use standard synchros.

The following table gives a comprehensive breakdown of all types and sizes of standard and prestandard synchros.

Table 2. Comparison of Primary Terminology

Military Standard	Prestandard
C - Control T - Torque X - Transmitter R - Receiver D - Differential CT - Control Transformer B - Rotatable Stator	G - Generator D - Differential Motor DG - Differential Generator CT - Control Transformer F - Flange-Mounted B - Bearing-Mounted N - Nozzle-Mounted H - High Speed (Over 300 RPM) S - Special Unit (No Mk and Mod assigned)
1. Designation does not denote manner of mounting. 2. Designation does not denote high speed, low speed, or special units. 3. Designation (26V-11CT4b) indicates: a. Unusual excitation (26V) b. Diameter of synchro (11) c. Functional classification (CT) d. Operating frequency (4 = 400 cycles) e. Modification of basic unit (b)	1. Mod denotes Manufacturer. (Mod 2 denotes G. E. as manufacturer, "a" being the first improvement of the modification.) 2. Units other than motors are flange-mounted unless B or N occurs in the designation.

MILITARY SYNCHRO TYPES

Summary

The military-standard type-designation code has been used for all synchros manufactured since 1949.

If the designation code on a synchro decal or nameplate is 23TR4b, the synchro is a standard type, is 2.3 inches in diameter, is a torque receiver, and is operated at 115 volts, 400 cycles per second. The "b" suffix indicates that some change, either mechanical or electrical, has been made in the synchro since the last specification was written. If the decal lists 26v23TR4b, the synchro is operated at 26 volts, 400-cycle excited.

Only two designations are carryovers from the prestandard to the standard type synchros. These are: the "B" designation for a bearing-mounted stator and the "CT" designation for control transformer.

STUDENT NOTES

TOPIC 5: HARDWARE, TOOLS, AND SYNCHRO MOUNTING METHODS

You Are Now Going to Learn:

1. Types of hardware used when mounting synchros.
2. Types of tools used when mounting synchros.
3. Types of synchro mountings and the method for each.

Discussion Points for This Topic Are:

1. Mounting clamp assemblies.
2. Clamping disc assemblies.
3. Adapter assemblies.
4. Zeroing rings.
5. Shaft drive washers.
6. Shaft drive nuts.
7. Shaft drive screws.

ASSIGNMENT:

OP 1303 (First Revision), pages 51-62.

PURPOSE:

To become familiar with the different synchro mounting methods and the tools and hardware used with each method.

TOPIC 5. HARDWARE, TOOLS, AND SYNCHRO MOUNTING METHODS

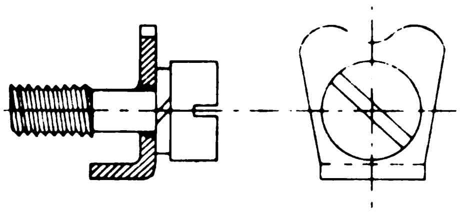
Synchro Hardware

The hardware commonly used with synchros are mounting clamp assemblies, clamping disc assemblies, adapter assemblies, zeroing rings, shaft drive nuts, shaft drive screws, and shaft drive washers. The hardware is standardized with regard to size, shape, and application.

Mounting clamp assemblies, clamping disc assemblies, and adapter assemblies are used to secure synchros to the chassis plates of instruments; the actual method of mounting determines the hardware to be used. In addition, the clamping disc assembly and the adapter assembly are used to provide precision angular adjustment of the synchro as well as to secure the synchro to a chassis plate. These units are secured directly to the synchro housing.

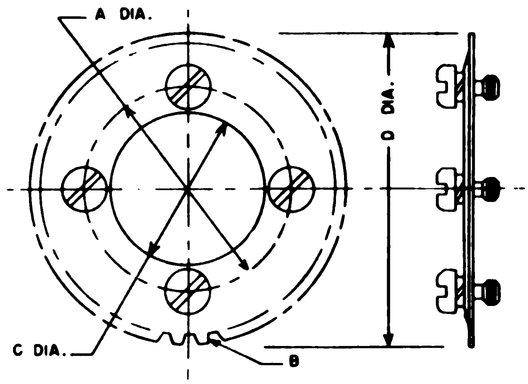
The combination of zeroing rings and mounting clamp assemblies is also used for angular adjustment of the synchro housing and to secure the unit to a mounting plate or chassis. In the latter instance, the zeroing ring is not directly secured to the synchro case but only rests on the mounting collar of the synchro. A protruding ear on the zeroing ring engages a slot in the mounting collar of the synchro. Three mounting clamp assemblies are used to secure the synchro and zeroing ring to the chassis plate.

Shaft drive washers, shaft drive nuts, and shaft drive screws are units of hardware used to secure dials or gears or both at the same time to the emergent shaft of a synchro. Drive nuts are used to compress drive washers and to lock the drive washers to the mounted gear or dial to prevent backlash. They are manufactured in three sizes to fit all emergent shafts of standard synchros.

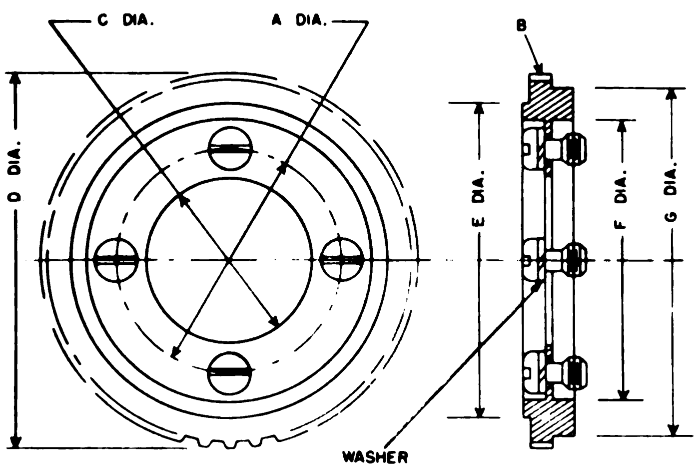


41. Mounting Clamp Assembly

Synchro Hardware (Continued)

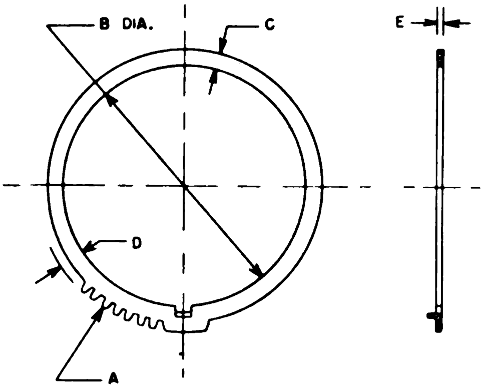


42. Clamping Disc Assemblies



43. Adapter Assemblies

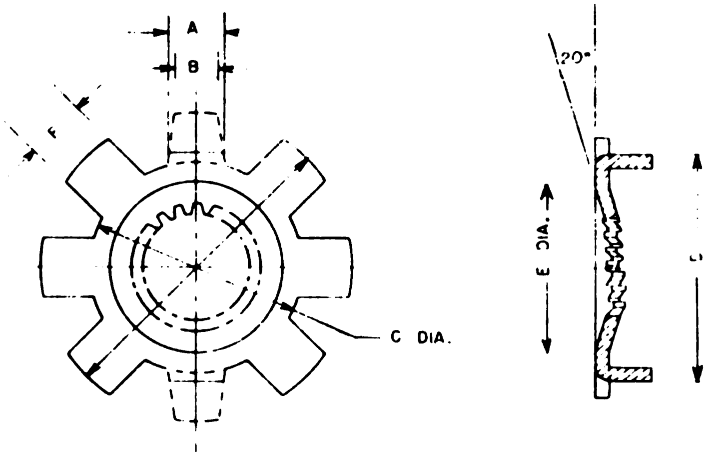
Synchro Hardware (Continued)



44. Zeroing Rings

Synchro Hardware (Continued)

Drive washers are manufactured from brass or aluminum sheets of different thicknesses; these washers are internally splined to fit the outside diameter of the splined shafts of standard synchros. Six tabs are provided on the drive washer to be bent around the drive screw or drive nut so that they cannot back off the shaft. Two tapered dogs are also provided to prevent backlash by engaging holes in the dial or gear being mounted. Some standard synchros have their emergent shafts drilled axially and tapped to receive a standard drive screw. These screws are used to compress and lock the drive washer to the mounted part such as a dial hub or gear. Since the washers are softer than the shaft, they will be slightly deformed because they have been compressed against the dial or gear by the drive screw or drive nut.

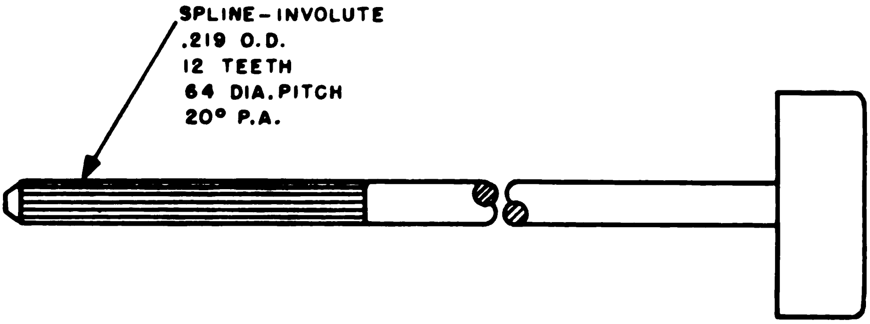


45. Drive Washers

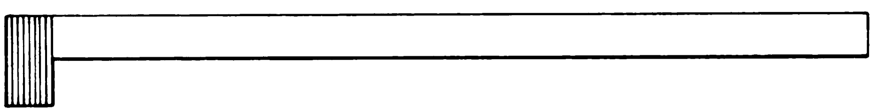
Prestandard synchro hardware consisted of slotted washers, thrust washers, drive nuts, and drive screws. None of these items were standardized as they now are for standard synchros. Most prestandard synchros had two flat sides 180° apart on the emergent shaft which received the special slotted washer.

Synchro Tools

There are two pinion wrenches specially designed to rotate the case of a synchro: a straight pinion wrench and a 90° pinion wrench. These are to be used with clamping discs, adapters, and zeroing rings when adjusting synchros for electrical zero. Both pinion wrenches are splined to fit adapters, clamping discs, and zeroing rings.



46. Straight Pinion Wrench

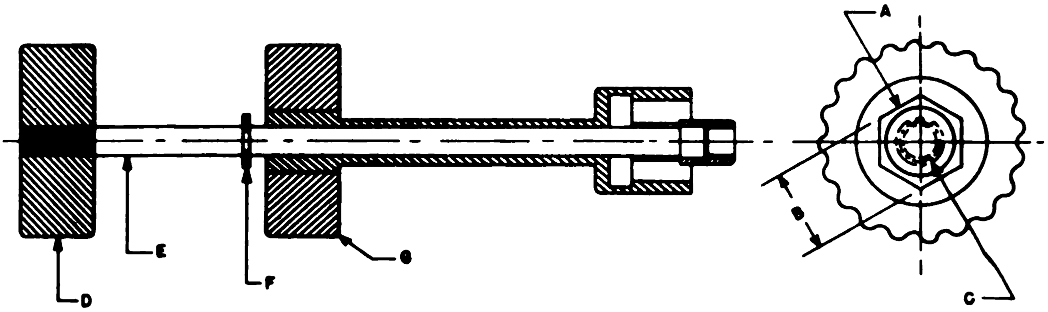


47. 90° Pinion Wrench

Three sizes of special socket wrenches have been designed to tighten drive nuts on a synchro shaft while holding the splined shaft. These wrenches have an internal shaft with a splined socket in the end of the shaft for holding the emergent synchro shaft steady. The outside shaft of the wrench has a hexagonal socket for tightening the drive nut.

Synchro Tools (Continued)

In addition to the special tools needed when working with synchros, the correct size of screwdrivers and box- or open-end wrenches should be readily available.

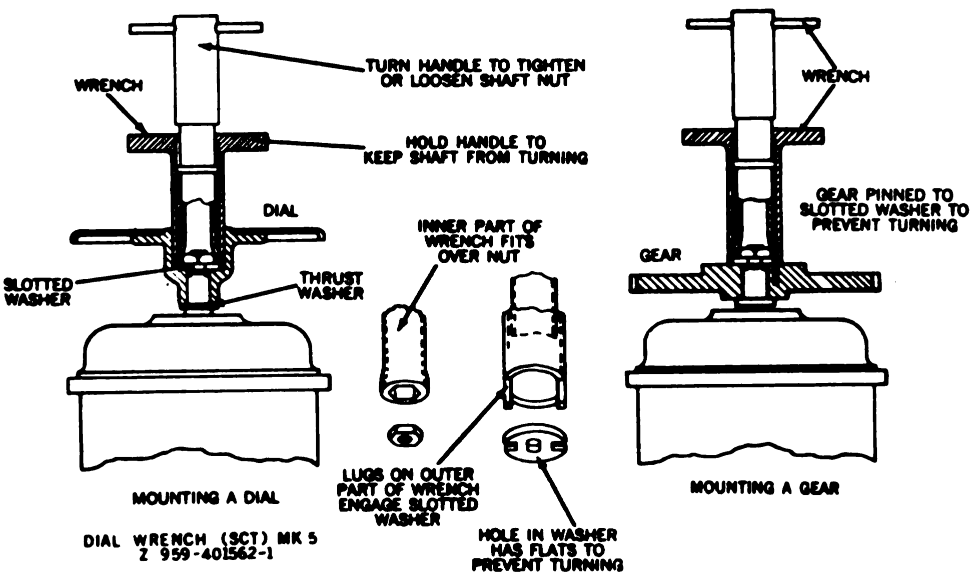


48. Socket Wrenches

Dials and counters driven by synchros are of many sizes and shapes. Common types are disc dials, ring dials, pointers, and odometer-type counters. Mounting methods for these common-type indicators vary with the particular instrument using the synchro system.

Synchro Tools (Continued)

The only special prestandard synchro tool is a dial wrench designed somewhat like the special socket wrenches used with standard synchros. The dial wrench has two protruding lugs on the outer shaft to engage the slots in the slotted washer. The inner shaft is a socket wrench used to tighten the drive nut, whereas the outer shaft holds the slotted washer engaging the flattened synchro shaft. This procedure locks the mounted dial hub or gear to the synchro shaft.

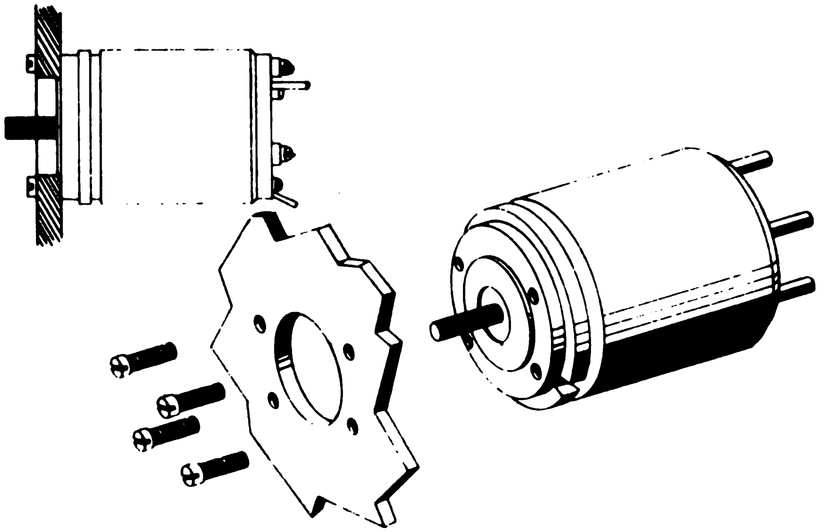


49. Prestandard Synchro Gear and Dial Mountings

Synchro Mounting Methods

Various methods are used to mount standard synchros in instruments; the particular mounting method that should be used is determined by the type of synchro and its application in the instrument.

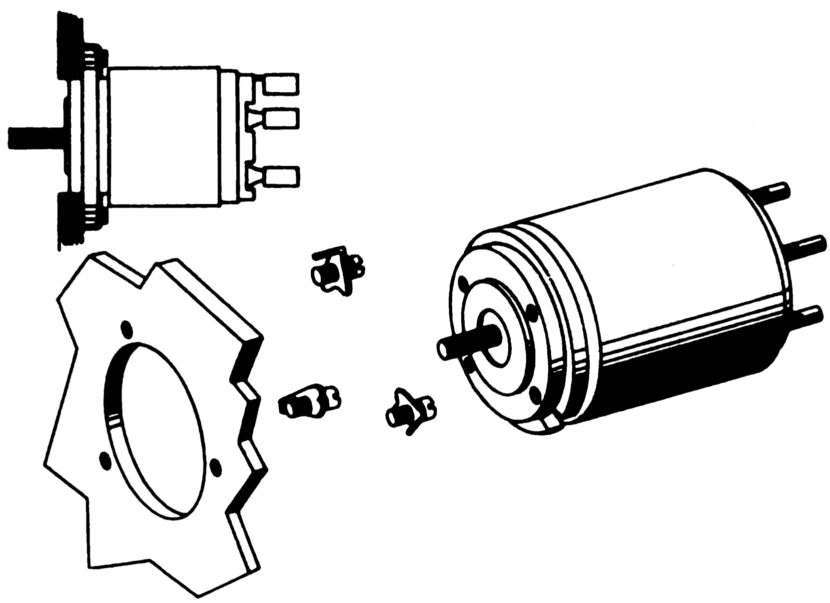
Units that do not require rotation of the case for zeroing may be mounted as illustrated. Four clearance holes are drilled in the shoulder of the chassis mounting hole to receive four screws to be screwed into the four, matching, tapped holes in the housing of the synchro. Control transformers are sometimes mounted in this manner.



50. Control Transformer, Military Standard Mounting, Showing the Method of Mounting from Shaft End When No Angular Adjustment Is Required

Synchro Mounting Methods (Continued)

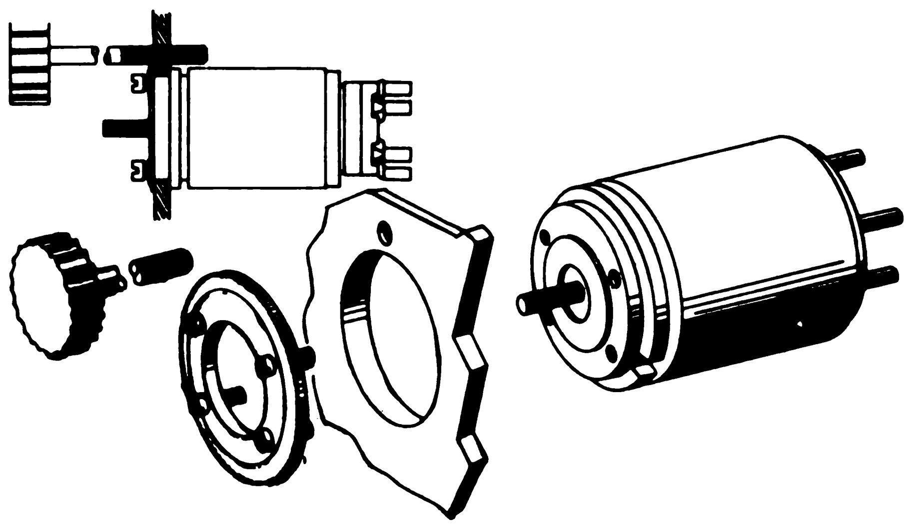
Three clamp assemblies are designed to bear on a mounting shoulder around the housing of the synchro and on the shoulder of the mounting hole in the chassis of the instrument. The screws of the mounting clamps are of the same size as the drilled and tapped holes spaced 120° apart on the shoulder of the mounting hole.



51. Synchro Mounting with Clamp Assemblies, Showing the Suggested Method of Mounting When the Shaft End Is Inserted Through the Mounting Plate

Synchro Mounting Methods (Continued)

Clamping disc assemblies are nothing more than gears with four clearance holes drilled in the body of the gear. These holes are drilled to allow screws to be inserted through them and into tapped holes in the housing of the synchro.

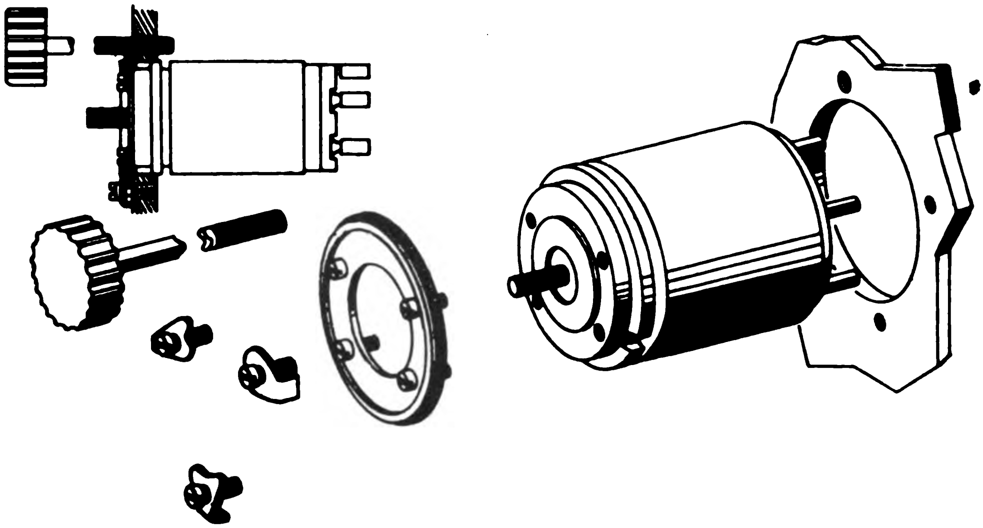


52. Synchro Mounting with Clamping Disc Assembly

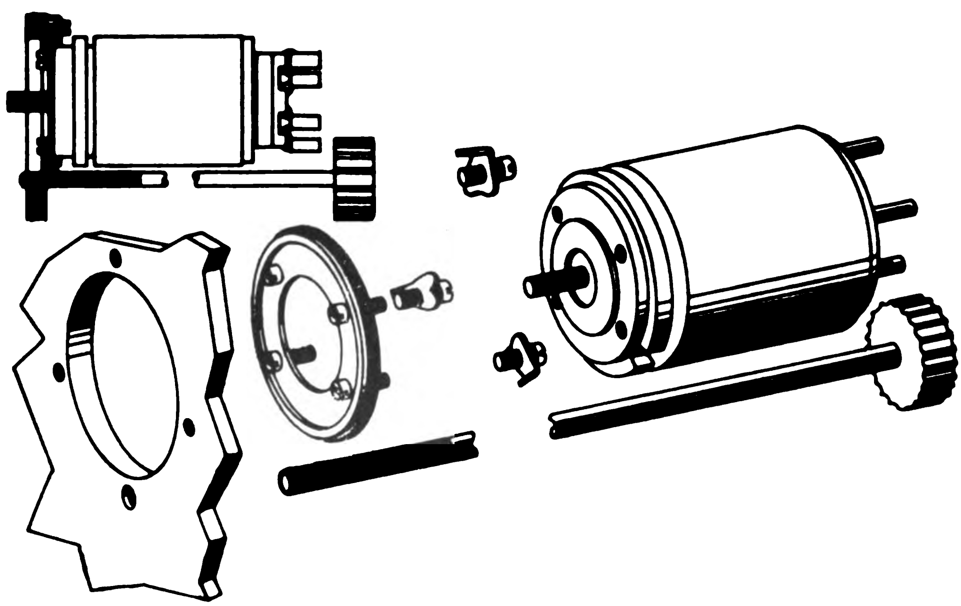
These screws clamp the chassis plate between the geared clamping disc and a shoulder on the synchro housing. The clamping disc is used to adjust electrical zero of the synchro by rotating the pinion wrench engaged to the gear edge of the clamping disc. A straight hole is drilled in the chassis plate to receive the pinion wrench. Before any adjustment is attempted, the four screws of the clamping disc assembly must be loosened.

Adapter assemblies are a combination of the clamping disc and three clamp assemblies. This combination is used to mount a synchro on a chassis plate when the terminal board end or the emergent shaft end is inserted through the mounting hole in the chassis plate.

Synchro Mounting Methods (Continued)



53. Synchro Mounting with Adapter Assembly, Showing the Method of Mounting When the Terminal End Is Inserted Through the Mounting Plate



54. Synchro Mounting with Adapter Assembly, Showing the Method of Mounting When the Shaft End Is inserted Through the Mounting Plate

Synchro Mounting Methods (Continued)

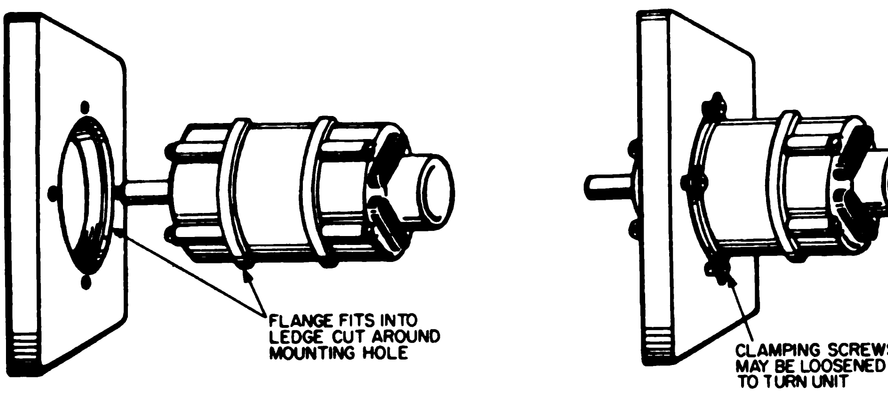
In either application, the adjustable clamping disc is first secured to the synchro housing using four screws; then the three clamp assemblies are screwed into the chassis plate with the ears of the clamp plates bearing on the clamping disc. This procedure sandwiches the clamping disc between the ears of the clamp plates and the chassis plate. Adjustment for electrical zero of a synchro mounted in this manner should not be attempted until the screws of the clamp assemblies are loosened slightly.

Zeroing rings and three clamp assemblies are used to secure a synchro to a chassis plate in the same way as the adapter assemblies. The zeroing ring is not secured to the synchro housing as is the clamping disc. A lug on the zeroing ring engages a slot on the mounting shoulder of the synchro housing. The three clamp assemblies are screwed into the chassis plate with the ears of each clamp plate bearing on the shoulder machined on the housing of the synchro. The zeroing ring is then clamped between the shoulder on the synchro housing and the chassis plate. Zeroing of a synchro mounted in this manner is accomplished by first loosening the three clamp screws. A pinion wrench (straight or 90° angle) is then inserted into the hole bored in the chassis plate for the purpose of aligning the wrench splines with the gear segment on the zeroing ring.

Military standard synchros with rotatable stators differ from prestandard synchros in that the housing of the standard synchro is secured to the mounting plate and the stator is rotated inside the housing. Prestandard synchros have the stator secured to the housing, and the synchros are mounted in bearings so that the housing is rotatable.

Synchro Mounting Methods (Continued)

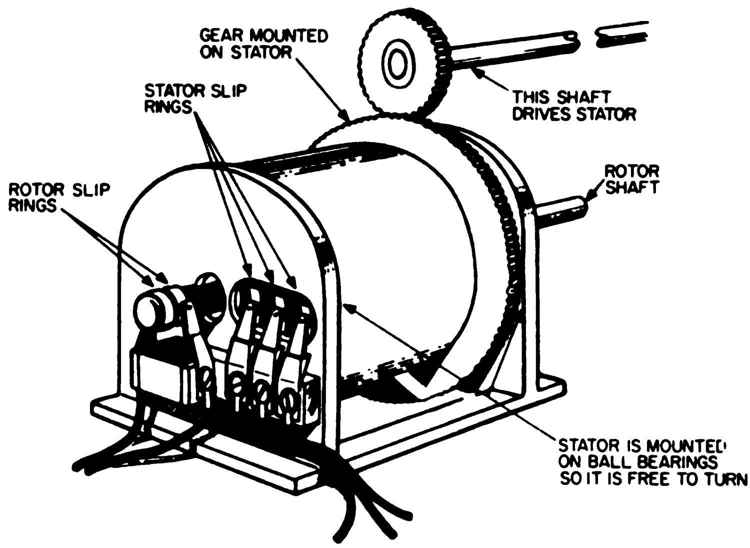
Prestandard synchro housings are designed to be mounted in only three ways. The most common type is flange-mounted. This way of mounting closely resembles standard synchro-mounting procedures using three or four mounting clamp assemblies. This type of mounting is designated "F" only with synchro receivers and is assumed with all other synchro units.



55. Typical Mounting of a Flange-Mounted Synchro

Synchro Mounting Methods (Continued)

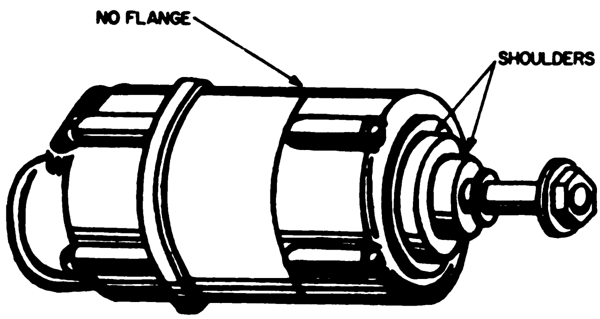
Bearing-mounted synchros are secured to a chassis plate by two supports containing bearing races. The synchro is mounted between these two supports resting on the flanges around the synchro housing. A gear around the body of the synchro positions the stator to an incoming mechanical signal. Units mounted in this manner will have a "B" in the designation.



56. Typical Mounting of a Bearing-Mounted Synchro

Synchro Mounting Methods (Continued)

A nozzle-mounted prestandard synchro will have an "N" in the designation. This type of mounting is not common. A synchro mounted this way has a special shoulder machined into the housing on the emergent shaft end for the purpose of receiving a press fit bearing; the synchro is usually mounted with the shaft end down.



57. Nozzle-Mounted Prestandard Synchro

Summary

Standardized hardware used with military standard synchros are clamp assemblies, clamping disc assemblies, adapter assemblies, zeroing rings, shaft drive nuts, drive washers, and drive screws. Prestandard synchros have no standardized hardware.

Tools used with standard synchros are pinion wrenches (straight and 90°-angle) and three sizes of socket wrenches.

Several different sizes of dial wrenches similar to the socket wrenches for military standard synchros have been designed for prestandard synchros.

Summary (Continued)

Military standard synchros may be mounted in many different ways, but only the zeroing-ring-and-clamp-assembly mounting method may be used on standard synchros.

Prestandard synchros may be mounted in one of three ways: flange-mounted, bearing-mounted, or nozzle-mounted. The most common of these is flange-mounted.

STUDENT NOTES

TOPIC 6: ZEROING SYNCHROS

You Are Now Going to Learn:

1. Electric-lock zeroing method.
2. Voltmeter zeroing method.

Discussion Points for This Topic Are:

1. Performance accuracy.
2. Reference points.

ASSIGNMENT:

OP 1303 (First Revision), pages 74-81.

PURPOSE:

To understand the reason for and the method of zeroing synchros.

TOPIC 6: ZEROING SYNCHROS

Performance Accuracy

The accuracy of a synchro is generally defined as the difference between intended performance and actual performance. Synchros must be accurate to be useful; to be accurate, they must be connected properly and aligned to a common reference point. Electrical zero is this common reference point.

Electrical Zero

When measuring the output voltage across any two of the three stator windings of a synchro transmitter or receiver, a zero voltage output will be obtained at two rotor positions 180° apart. To arbitrarily choose one of these points as electrical zero would not be sufficient to define electrical zero clearly. Should any one stator winding be parallel to the rotor winding? Should any one stator winding be perpendicular to the rotor winding? More important, across which two stator windings should voltage measurements be taken? The answers to questions such as these limit the number of rotor positions which will meet the conditional requirements of electrical zero.

For synchro transmitters and receivers, electrical-zero voltage measurements should be made across the S1 and S3 stator windings. Electrical zero is further defined for these synchros as the one position where the S2 stator winding is parallel to the rotor winding.

When the stator of a control transformer is receiving excitation from a transmitter (TX or CX) which is at its electrical zero position, and when the rotor of the CT is producing minimum voltage output, the CT is said to be at its electrical zero position if counterclockwise rotor movement produces an R1-R2 rotor voltage that is in-phase with the R1-R2 rotor voltage of the TX or CX.

For synchro differential transmitters and receivers, electrical-zero voltage measurements should be made across the R1 and R3 rotor windings. A further stipulation for the exact position is that the R2 and S2 windings be parallel.

All synchros in a system should be aligned to a common mechanical reference point as well as to their individual electrical zero reference positions. Synchro systems that are used, for example, to indicate range use 10,000 yards as a mechanical reference point. All units within this particular system must be mechanically and electrically aligned to this reference point.

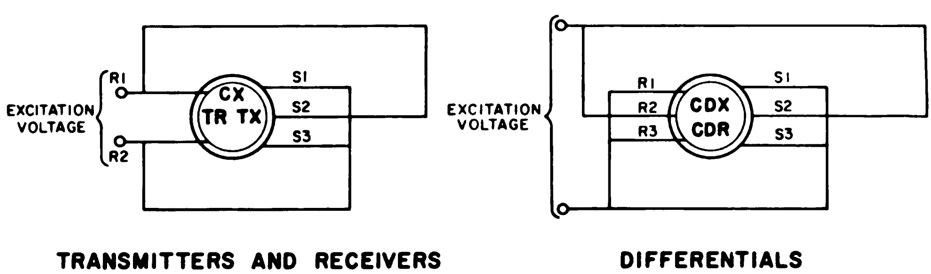
ZEROING SYNCHROS

Zeroing Methods

Military standard synchros have the correct coarse-electrical-zero position stamped on the case and rotor shaft. Prestandard synchros do not have this marking.

Some installations of military standard synchros are such that the coarse electrical zero markings cannot be visually checked. In these instances and in all systems using prestandard synchros, coarse electrical zeroing tests must be performed before the fine electrical zeroing tests are attempted.

A common zeroing method, the electric-lock zeroing method, is shown in the accompanying illustration. One advantage of this method is that one man can do the job. One disadvantage however, is that a source of 78 volts is required to use this method safety. If a 78-volt supply is not available, 115 volts can be used; but this value of excitation should not be used for more than two minutes. Excitation exceeding the rated value of the synchro will cause the unit to overheat.



58. Electric-Lock Zeroing Method

CAUTION: The synchro rotor must be free to turn before the electric-lock zeroing method is used.

The electric-lock method of zeroing is practical only when the synchro lead connections are accessible. When this method is used, however, the synchro will assume the true electrical zero position.

Zeroing Methods (Continued)

The most accurate method of zeroing a synchro is the voltmeter method. The procedure and the test-circuit configuration for this method vary somewhat, depending upon which type of synchro is to be zeroed. Transmitters and receivers, differentials, and control transformers each require different test-circuit configurations. Also, the procedure for zeroing a unit whose rotor or stator is not free to turn may differ from the procedure for zeroing a similar unit whose rotor or stator is free to turn.

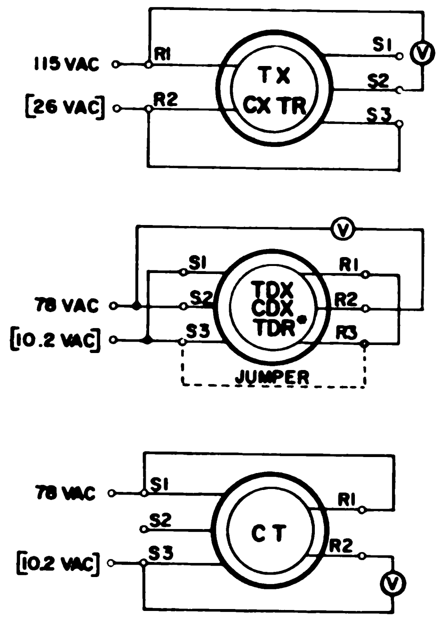
Chapter 6 of OP 1303 (First Revision) lists in detail the correct procedure for a variety of zeroing methods applying to all types of synchro-units; therefore, this manual will list only the most common one, the voltmeter method.

The two accompanying illustrations list excitation values for both 115-volt and 26-volt synchro units. Excitation values for the 26-volt units are enclosed in parentheses.

The illustrated test-circuitconfigurations applying to all TX and CX synchros also applies to those TR units whose rotors are free to turn. It is important to note that when performing the coarse test on a TR, a jumper should be placed across S1 and S3. A voltmeter indication of approximately 40 volts (15 volts) will then prove that the TR rotor is near its true electrical zero position.

The illustrated test-circuit configuration applying to all TDX and CDX synchros also applies to those TDR units whose rotors are not free to turn.

Zeroing Methods (Continued)



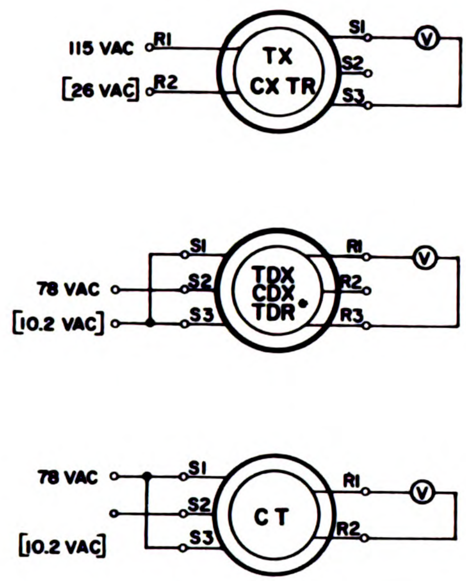
59. Voltmeter Zeroing Method, Coarse Settings

*Applies to those TDR synchros whose rotors are not free to turn.

The general procedure for zeroing most types of synchro units by the voltmeter method is as follows:

1. Remove all connections except those from which excitation is received.
2. Position the unit's rotor (or stator) as close as possible to the zero reference position. For differentials and receivers, this may be done by first zeroing the transmitter.
3. Establish the required test circuit.
4. Position the unit's rotor (or stator) for minimum voltage indication.

Zeroing Methods (Continued)



60. Voltmeter Zeroing Method, Fine Settings

*Applies to those TDR synchros whose rotors are not free to turn.

Summary

There are many ways to zero a synchro. One method is the electric-lock method. This cannot always be used because of the way in which some synchros are installed in instruments or equipment; however, by disconnecting any mechanical connection to the rotor of a synchro, this electric-lock method can be used.

Most manufacturers, engineers, and maintenance men agree that the voltmeter method should be adopted as the standard method of zeroing a synchro. The voltmeter method can be used on all synchros regardless of their method of installation.

TOPIC 7: SYNCHRO TROUBLES

You Are Now Going to Learn:

1. Problems of synchro maintenance.
2. Rules for maintaining synchros.
3. Common trouble symptoms.

Discussion Points for This Topic Are:

1. Trouble indications.
2. Trouble indicators.
3. Troubleshooting techniques.

ASSIGNMENT:

OP 1303 (First Revision), pages 82-90.

PURPOSE:

To become familiar with the common casualties affecting synchros and with the general methods of removing these casualties.

TOPIC 7. SYNCHRO TROUBLES

Synchro Maintenance Problems

Some synchro units in use in the Navy today have been operating for years without lubrication or overhaul. This does not mean, however, that synchro maintenance problems are nonexistent. Maintenance problems can occur in any synchro system.

There are three general rules for maintaining synchros:

1. Do not disturb a synchro if it is working satisfactorily.
2. Replace a synchro only when it becomes defective.
3. Never lubricate a synchro.

Since synchro installations aboard ships or aircraft are of the same basic types, they have the same basic casualties. In general, casualties peculiar to new synchro installations fall into three categories:

1. Units are not zeroed correctly.
2. Wiring between units is reversed.
3. Terminal connections are loose.

Ordnance failure reports indicate that common synchro casualties in systems that have been in operation for a considerable period of time occur most frequently in the following order:

1. Rusty or frozen synchro bearings
2. Open or shorted rotor or stator windings
3. Dirty sliprings or worn brushes
4. Oil or water leakage into a synchro from surrounding components
5. Defective dampers

Synchro Maintenance Problems (Continued)

One casualty attributable to human error and common to both new and old systems is incorrect positioning of switches.

The proper corrective action for any casualty to a synchro unit is to replace that unit. No attempt should be made to disassemble a synchro for any purpose.

Troubleshooting the interconnecting wiring between synchros can be accomplished with the use of an AC voltmeter and an appropriate synchro tester for testing the excitation voltage. Frequent casualties that occur in the interconnecting wiring are: loose connections, caused by vibration and frayed wires and reversals, caused by improper maintenance by inexperienced or careless personnel.

Overload indicators and blown fuses are trouble indications that aid the maintenance technician in locating faulty components or faulty wiring.

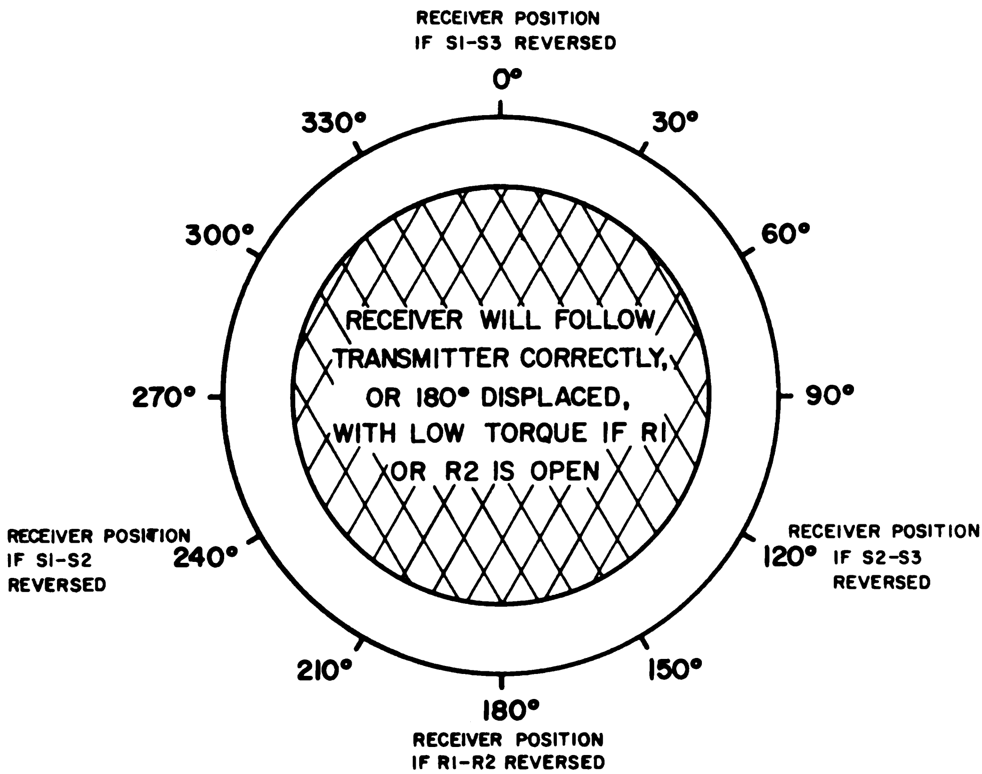
One example of an overload indicator is a neon lamp that is wired in series with the secondary windings of two step-up transformers. The primary of one transformer is in series with the S1 stator circuit of a transmitter and receiver. The primary of the second transformer is in series with the S3 stator circuit.

If at any time the receiver is overloaded, it will lag the transmitter. This lag will cause an unbalance in the S1 and the S3 stator circuits, inducing an unbalance in the two secondary windings. The greater the overload, the greater the receiver lag. The greater the lag, the greater the unbalance. The amount of unbalance necessary to light the neon lamp is determined by the step-up ratio of the two transformers.

The neon-lamp indicator is generally mounted in the switchboard which controls the particular synchro system.

Common Trouble Symptoms

Common trouble symptoms and their probable causes in a torque-type synchro system are charted on the following pages. These charts refer to only one receiver connected to a transmitter, but the same symptoms occurring in multiple receiver systems will have the same probable causes.



RECEIVER WILL ACT AS INDICATED ON CHART IF TRANSMITTER IS ON 0°

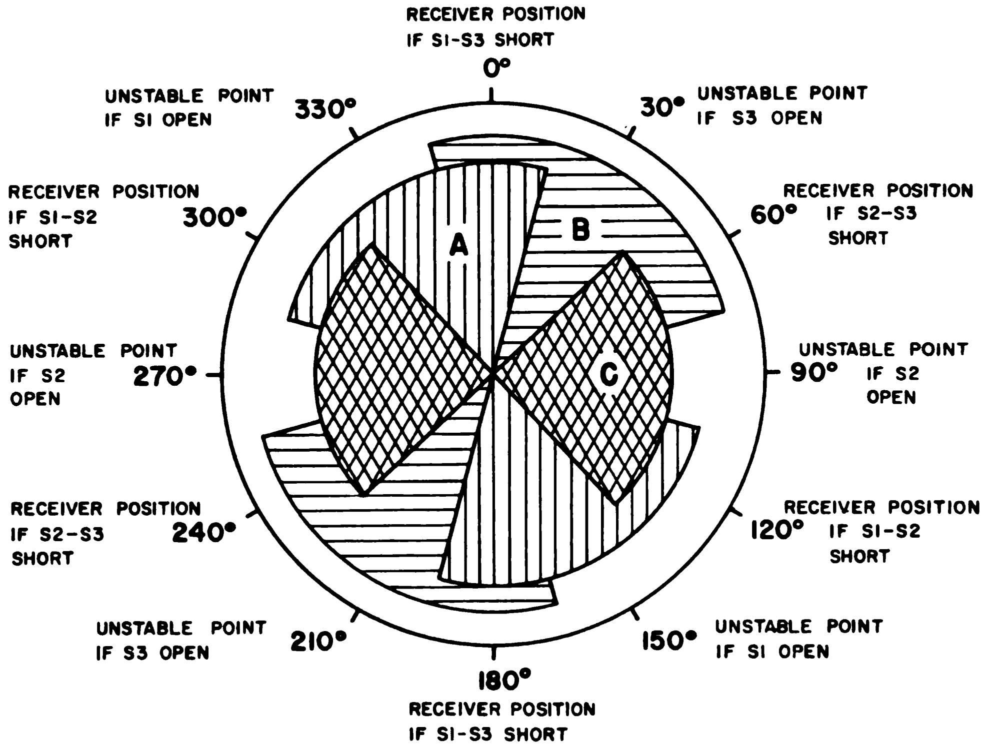
RECEIVER WILL ROTATE OPPOSITE TO TRANSMITTER IF ANY TWO S LEADS ARE REVERSED

RECEIVER WILL FOLLOW CORRECT ROTATION WITH 120° ERROR IF ALL S LEADS ARE ROTATED CLOCKWISE ONE PLACE

RECEIVER WILL FOLLOW CORRECT ROTATION WITH 240° ERROR IF ALL S LEADS ARE ROTATED COUNTERCLOCKWISE ONE PLACE

61. Common Trouble Symptoms Caused by Connection Reversals

Common Trouble Symptoms (Continued)



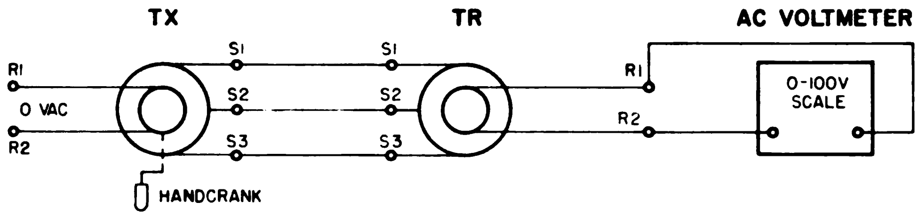
ROTATE TRANSMITTER THROUGH 360° AND RECEIVER WILL USUALLY ACT AS INDICATED ON CHART.

62. Common Trouble Symptoms Caused by Shorted or Open Connections

The voltage balance test serves as a check on the output voltages of the stator of a torque transmitter. It would be necessary to run this type of test on a transmitter if all the receivers in the system acted erratically at the same transmission angles. To conduct the voltage balance test, use any good AC voltmeter and a torque receiver in perfect condition.

Common Trouble Symptoms (Continued)

The torque transmitter rotor leads are connected to the correct excitation source and the stator leads to the correct stator leads of the receiver. The voltmeter is connected to the synchro's receiver rotor leads as illustrated.˙ Voltage scale selector should be set at 0 to 100 VAC.



63. Voltage Balance Check

The rotor of the torque transmitter should be turned smoothly clockwise through 360° rotation while monitoring the AC voltmeter. Next, the rotor is turned counterclockwise through 360° rotation while the voltmeter is monitored. Maximum allowable voltage change is less than two volts. Any voltage indication exceeding the allowable should be rechecked before replacing the TX.

Oscillation or hunting in any synchro system is a major trouble. There are two types of oscillations in torque synchro systems: those caused by switching and those caused by casualties. Some systems always have oscillation caused by the sequence in which the units are energized. This is known as switching oscillation and may be kept to a minimum by correct switchboard operation. A good example of this type of oscillation is the ships course receivers used in directors and weapon control stations. If these receivers are not energized at the same time as the ships course receivers on the bridge and in CIC, they will cause momentary oscillations throughout the system when they are energized. This situation is objectionable, especially if the ship is fueling or provisioning underway and steaming parallel to the oiler or provision ship. All receivers of a system should be energized immediately after the transmitter, even though a particular receiver is not going to be used at that instant.

Common Trouble Symptoms (Continued)

Shorted stator leads or open or shorted damper windings may cause either spinning or oscillations. Occasionally, these same casualties may cause a rapid flopping from the indicated position of the receiver to another position 180° from the transmitted position.

Summary

There are three basic rules for maintaining synchros:

1. Leave synchros alone if they work.
2. Replace synchros if they become defective.
3. Never lubricate a synchro.

Common casualties to synchro systems in new installations are:

1. Units are not zeroed correctly.
2. Wiring between units is reversed.
3. Terminal connnections are loose.

Common casualties usually occurring in systems that have had no preventive maintenance or inspection for a long period of time are:

1. Rusty or frozen synchro bearings
2. Open or shorted rotor or stator windings
3. Dirty sliprings or worn brushes
4. Oil or water leakage into a synchro from surrounding components
5. Defective dampers.

One casualty attributable to human error and common to both new and old systems is the correct positioning of switches.

Overload indicators and blown fuse indicators along with a good AC voltmeter and synchro tester are useful in correcting casualties in a synchro system.

STUDENT NOTES

TOPIC 8: MULTISPEED SYNCHRO SYSTEMS

You Are Now Going to Learn:

1. Definition of a single-speed synchro system.
2. Definition of a multispeed synchro system.
3. Terms which describe the two speeds of a dual-speed synchro system.
4. Functional operation of a dual-speed synchro system.
5. Causes of possible false synchronization in multispeed synchro systems.
6. Reasons for the increase in accuracy when higher speed ratios are used.
7. Applications of multispeed synchro systems.

Discussion Points for This Topic Are:

1. Data transmission speeds.
2. Gear ratio and speed ratio.
3. Coarse and fine speeds.
4. Apparent or false synchronization points.
5. Cumulative error.
6. Error reduction.

ASSIGNMENT:

OP 1303 (First Revision), pages 24-25.

PURPOSE:

To learn what is meant by the term multispeed; how a multispeed synchro system functions; and why an increase in the multiple of speed produces an increase in the accuracy of the system output.

TOPIC 8: MULTISPEED SYNCHRO SYSTEMS

Data Transmission with Multispeed Systems

If the input and output shafts of a synchro system rotate through equal arcs while the rotors of the synchro transmitter and receiver in the system turn through equal arcs, the synchro system is a single speed or one speed system. In such systems, there is only one output shaft. The speed at which data is passed on the output shaft is the same as the speed at which data is accepted on the input shaft.

Multispeed synchro systems are those systems that use more than one speed of data transmission; thus, they require more than one output shaft. A dual speed system, for example, transmits data at two different speeds. Likewise, a three speed system transmits data at three different speeds.

The two speeds of a dual-speed synchro system are often referred to as the fast and slow, or the high and low, or more acceptably as the coarse and fine.

A basic dual-speed synchro system consists of two transmitters and two receivers. One transmitter receives the external input to the system and, through a network of gears, passes the effects of the external input to the second transmitter. The gear ratio between these two transmitters determines the two specific speeds which the system will use to transmit the input data.

If, for example, the gear ratio between the two transmitters is 36:1, one revolution of the rotor of the first transmitter causes 36 revolutions of the rotor of the second transmitter. Thus, the first transmitter - the one which accepts the external input - can be called the coarse transmitter, and the second one can be called the fine transmitter.

The outputs of each transmitter are passed through standard synchro connections to a receiver; hence, one receiver receives the coarse signal and the other one receives the fine signal. The two receivers may or may not be connected by a network of gears similar to the network between the two transmitters. Receiver gearing is not absolutely necessary for the system to operate; however, for continuously accurate operation, receiver gearing is essential.

Data Transmission with Multispeed Systems (Continued)

In a 1- and 36-speed dual-speed synchro system, one revolution of the rotor of the coarse transmitter causes 36 revolutions of the rotor of the fine transmitter. It follows that this action also produces one revolution of the rotor of the coarse receiver and 36 revolutions of the rotor of the fine receiver.

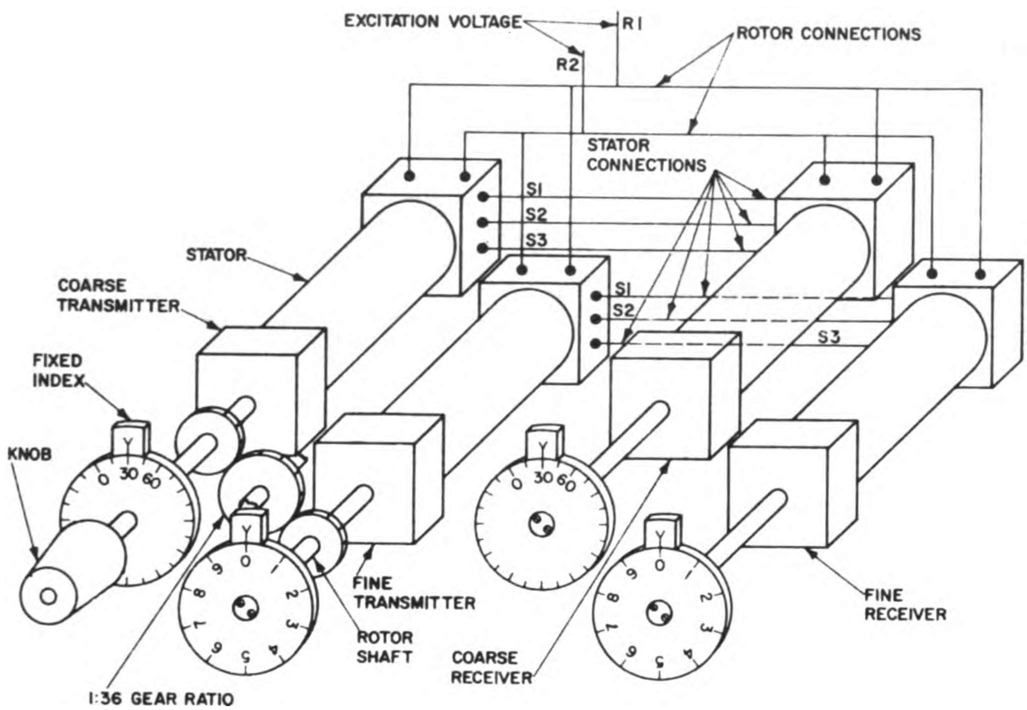
While the rotor of each coarse unit makes one revolution, it passes its 0° reference or synchronization point only once. Meanwhile, however, the rotor of each fine unit passes its synchronization point 36 times. The significance of this latter statement is that the fine receiver apparently has 36 synchronization points. Only one of these apparent points, however, can be the true synchronization point.

If, while the synchro system is deenergized, the rotor of the fine receiver is moved one complete revolution but the rotor of the coarse receiver is not moved, the output shaft of the fine receiver will be in error by an amount equal to one revolution when power is restored. To prevent this possibility, gearing is placed between the two receivers, hence, the rotor of one receiver mechanically follows the movement of the other. This gearing, therefore, is one method of removing the synchronization ambiguities of the fine receiver and, in turn, from the system. The transmission of torque-type and control-type dual-speed synchro systems is geared the same way.

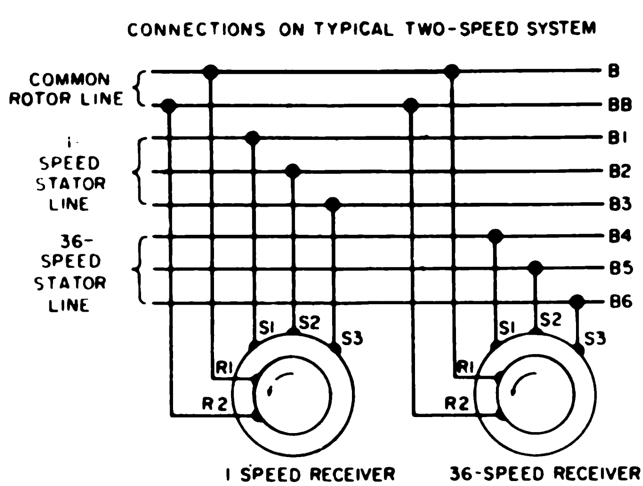
The receiver of a control-type system is a control transformer. Because the rotor of a CT is not energized, the error voltage induced into the rotor can be zero at two positions, the correct 0° reference position and 180° from the correct position. This feature complicates the problem of false synchronization by doubling the number of apparent synchronization points. This problem is corrected by adding a stick-off voltage in series with the CT rotor circuit. A discussion of this corrective measure is detailed in Topic 9 under the heading "The Stick-Off Transformer."

Most dual-speed control-type synchro systems are designed so that the voltage output of the coarse CT controls the servoamplifier to within 2.5° of synchronization. At this point, a mechanical or electrical device is actuated, allowing the fine CT to assume control of the servoamplifier. To prevent the ambiguities which could arise because of the many possible false null positions when the fine CT has control of the servoamplifier, the mechanical or electrical device is geared to the load. This assures that the system will be driven to the correct null position.

Data Transmission with Multispeed Systems (Continued)



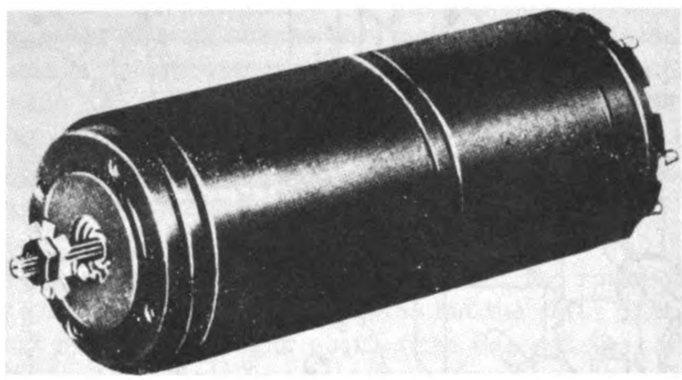
64. Typical Dual-Speed Torque Synchro System



65. Connections on Typical Dual-Speed Synchro Receivers

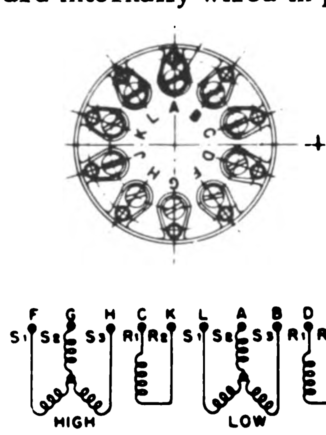
Data Transmission with Multispeed Systems (Continued)

A dual-speed torque synchro system requires only three more wires than the five wires used in a single speed system. Rotor connections are made from the same excitation source to all transmitters and receivers in either type of system. The three additional wires used in a dual-speed synchro system are used to connect the stators of the fine transmitter and fine receiver.



66. Double-Speed Control Transmitters

New types of synchro configurations in which two rotors and two stators are housed in the same case have recently been put into production. In most instances, these special types have been designed as control synchros. The gearing between the two rotors must be designed for each particular double-speed application; however, most are geared at 1 and 36 speeds or 2 and 36 speeds. The illustrated control-transmitter-connection-block diagram shows only terminals D and J for excitation input because the two rotors are internally wired in parallel.



67. Control Transmitter Connection Block

MULTISPEED SYNCHRO SYSTEMS

Accuracy of Multispeed Systems

Each synchro unit in a synchro system contributes a number of errors which affect the accuracy of the system. These errors are electrical errors, receiver errors, static errors, and the like. Combining all the individual errors affecting the accuracy of one unit produces the cumulative error for that unit. Similarly, combining the cumulative errors for all units in a system produces the cumulative error for that system.

By using multispeed data transmission, system errors may be effectively reduced. For example, in a 1- and 36-speed dual-speed synchro system, the input to the fine transmitter contains only 1/36 of the error in the output of the coarse transmitter. The cumulative error in the accuracy of the fine transmitter itself may add to or subtract from the error it receives from the coarse transmitter; however, the total error transmitted to the fine receiver is much less than that in the output of the coarse transmitter.

If the dial of the coarse receiver in this dual speed system is graduated in 10° increments, and if the dial of the fine receiver is graduated in 10" increments, an output will not only be more accurate but can also be read more accurately than if the data were transmitted by a single-speed synchro system.

The cumulative error affecting the accuracy of a synchro system used in a modern Navy installation ranges from twenty seconds (20") to one minute (1') of arc. The cumulative error in a system which used prestandard synchro units was as much as 1°.

Applications of Multispeed Synchro Systems

Double-speed synchro systems are used throughout the Navy in weapon systems, air and surface search systems, gyro compass transmission systems, and other types of systems which require a high degree of accuracy.

The bearing or train indication of a Mk 68 Gun Director is transmitted by a double-speed synchro system through the fire control switchboard to double-speed synchro receivers in the computer and in off-director indicators. The synchros used are prestandard-type, 5G torque transmitters operating on 115-volt, 60-cycle excitation. These synchros are mechanically turned at 1 and 36 speeds by the train gearing located on the underside of the director.

Accuracy of Multispeed Systems (Continued)

Elevation transmission is nearly identical to train transmission. The same types of synchros are used, 5G prestandard, but are geared to transmit at 2 and 36 speeds because of the limited arc of director elevation, 25° depression to 95° elevation.

Summary

If the input and output shafts of a synchro system rotate through equal arcs while the rotors of the synchro transmitters and receivers in the system turn through equal arcs, the synchro system is a one speed or single speed system.

Multispeed synchro systems are those systems that use more than one speed of data transmission; thus, they require more than one output shaft.

The two speeds of a dual speed system are called the coarse speed and the fine speed.

In a 1- and 36-speed dual-speed synchro system, one revolution of the coarse transmitter causes 36 revolutions of the fine transmitter. The coarse and fine receivers directly follow their transmitters.

Increasing the speed of data transmission decreases the system error but increases the number of possible false synchronization points. Mechanically gearing the fine receiver to the coarse receiver is one method commonly used to prevent false synchronization.

SECTION 3

SYNCHRO-SERVO SYSTEMS

Topic No.	Topic Title	Page
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2	Servoamplifiers (AC)	138
3	Servomotors (AC)	154
4	Response in Servo Systems	164
5	Antihunt in Servo Systems	174
6	DC Servo System	190
7	Servoamplifiers Using Thyratrons	212
8	Introduction to the Amplidyne	228
9	Dual-Speed Synchro-Servo System	236
10	Three-Speed Synchro-Servo System	248
11	Naval Applications of Synchro-Servo Systems .	254
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TOPIC 1. BASIC SERVO SYSTEM

You Are Now Going to Learn:

1. Basic components of a servo system.
2. Basic requirements of a servo system.
3. Servo terminology and definitions.
4. Classification of servos by use.
5. Servo system ratings.

Discussion Points for This Topic Are:

1. Servo system functions.
2. Servo terminology.
3. Standard Navy servos.
4. Velocity figure of merit.
5. Acceleration figure of merit.

ASSIGNMENT:

NAVPERS 10086-A, pages 374-378.

PURPOSE:

To become familiar with servo components, servo terminology, servo classifications, and servo system ratings.

TOPIC 1. BASIC SERVO SYSTEM

What a Servo Is

Servomechanisms, commonly called servos, are devices capable of initiating a controlled output motion at a high power level in response to a relatively small power input signal. Servos are part of a family of systems known as open loop and closed loop (feedback) control systems. Depending upon their particular application, servos may be hydraulic, pneumatic, electromechanical, and/or electronic. A servomechanism causes a mechanical action to take place on command.

This course is confined primarily to closed loop, electromechanical and electronic servomechanisms. These will familiarize the trainee with the application of servomechanisms to Naval fire control, sonar, missile launching and guidance systems, navigation, radar, and similar equipments requiring automatic control.

Basic Requirements of a Servo System

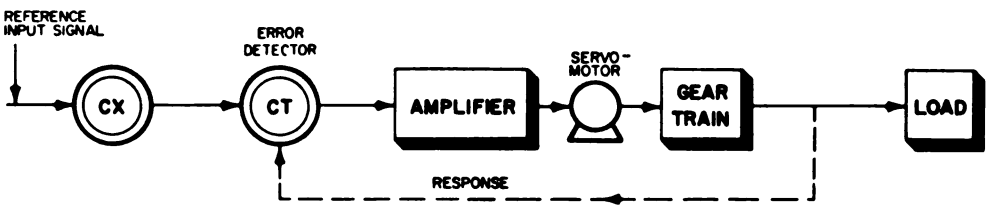
Automatic control systems must have the following basic characteristics in order to be classified as servos.

1. A servo must be capable of accepting an order which defines the desired result.
2. A servo must be capable of evaluating the present conditions.
3. A servo must be able to compare the desired result with the present conditions and to obtain a difference or an error signal.
4. A servo must be able to issue a correcting order, determined by the error signal, which will properly change the existing conditions to the desired result.
5. A servo must have the means to obey the correcting order.

In summary, a servo must be able to accept commands and to carry them out.

Basic Requirements of a Servo System (Continued)

The functional block diagram below represents a typical, closed loop, servo system. The operation of such a system, relative to the positioning of a gun or radar antenna represented by the "load" block, might be analyzed as follows:



68. Functional Block Diagram of a Typical Servo System

The synchro transmitter provides the reference input signal (order signal) to the error detector (control transformer), which in turn compares the order signal with the actual position of the load. This comparison results in a command (error signal) that is amplified by the servo-amplifier. A large amplification is necessary to operate the servomotor (power drive) which positions the heavy load. While the load is being moved toward the desired position, a mechanical or electrical response is continually and automatically fed back to the control transformer for comparison with the input order signal. When the load reaches the desired position, the error signal will have been reduced to zero.

The input position acts as a reference to which the output position must correspond. The output member or load is that part of the system which is driven to correspond to the input member. The error detector is the device which produces an error signal proportional to any difference between the input and output positions. The servomotor is activated by the error signal after the signal has been amplified. The servomotor can then deliver a force of sufficient power to drive the load, reducing and finally nulling the error signal. The response signal is continuously and automatically fed back from the load to the error detector for comparison with the reference input signal.

Basic Requirements of a Servo System (Continued)

The basic function of a servomechanism can be summarized as follows. A servomechanism compares the command position with the present position and converts any difference between these positions into an error signal. This error signal is amplified to create a proportional amount of power from the reference voltage. The difference between the reference voltage and the error-signal voltage generates an excitation voltage. The excitation voltage causes torque to develop in the servomotor, which drives the load to a position corresponding to the command position. The input signal to the error detector is nulled by response from the load to the error detector.

Servo Terminology and Definitions

The following terminology used to describe the components and the functions of servo systems is standard.

Open loop servo: The open loop servo is a servo in which the input does not depend upon the output nor is the input affected by the output. For example, the energy required to turn on a heater switch is independent of the energy released by the heater.

Closed loop servo: The closed loop servo is a servo which has a direct relationship between the load and the input signal. This relationship is maintained by the response of the load being compared to the input signal.

Error detector: An error detector is the component of a servo, usually a differential device, used to detect the difference between input signal and load position.

Overshooting: Overshooting is that condition occurring when the load drives past the input or ordered signal.

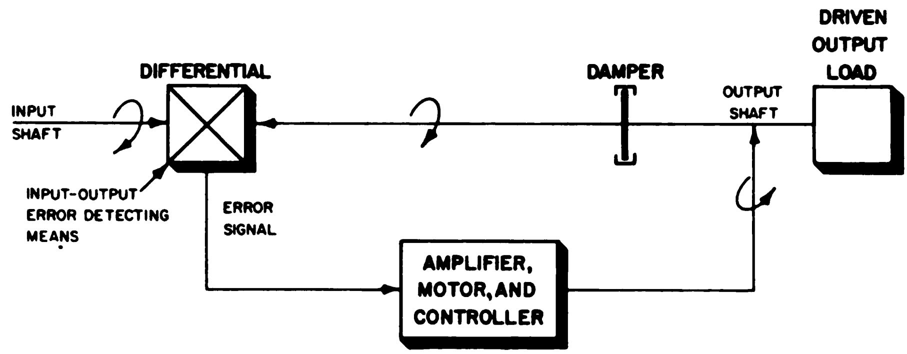
Oscillation: Oscillation is that condition occurring when the load hunts back and forth across the ordered position.

Servo Terminology and Definitions (Continued)

Error signal: The error signal is the corrective signal developed as a result of the difference between the ordered position and the present position of the load. When suitably amplified, the error signal controls the load power drive.

Classification of Servos by Use

Servos can be classified into groupings according to their use. The three most common classifications are: positioning servos, velocity servos, and acceleration servos.



69. Functional Block Diagram of Positioning Servo System

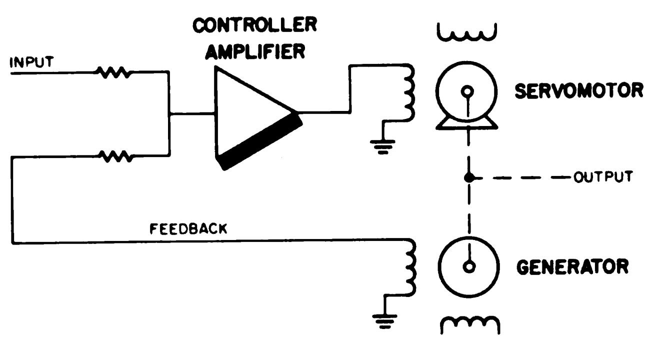
The illustrated positioning servo system is typical of most systems used in the Navy today for positioning guns, missile launchers, radar antennas, and the like. The servo drives the load to a position corresponding to the angular position of a control input shaft. To achieve this, the input shaft is connected to one side of a differential device; the load is connected to one of the other sides. Only a very small amount of power is required to drive either side of the differential, through which no energy is transferred from the input shaft to the load. The differential output assumes a position that is the difference or error between the position of the one input and the load. The output member of the differential actuates a controller. This controller uses an amplifier and a drive motor to drive the load in accordance with the error indications of the differential. If the system is at rest and the input shaft is suddenly repositioned, the difference between the input and output shaft will cause the differential to deflect from its original position. This deflection applies a signal to the controller, which then drives the load

Classification of Servos by Use (Continued)

so that the error indication is reduced to zero. Thus, the repositioning of the controller servo and its associated output load follows the position of the input shaft.

The velocity servo produces a motor-shaft velocity proportional to an input voltage, the total number of revolutions made by the motor shaft being the time function of the input voltage. Assuming that the internal loading, such as friction, is at zero, an ideal two-phase induction servomotor would run at the same speed as the rotating flux regardless of the applied voltage. As the motor slows down, the torque required to overcome these losses is developed by applying a feedback voltage added to the signal voltage. Since the load also requires torque, the actual speed of the shaft is proportional to the developed torque minus the load torque. Therefore, the motor velocity is a function of both the applied voltages and the load. The motor will compensate for velocity changes caused by varying loads.

A velocity servo usually incorporates a tachometer generator to produce feedback voltage. The block diagram illustrated is typical of most velocity servos.



70. Block Diagram of Velocity Servo

Classification of Servos by Use (Continued)

The feedback from the generator is proportional to the velocity at which the servomotor drives the generator. The input voltage from the controller to the motor is a function of the difference between the input voltage and the velocity of the output shaft. The inherent characteristic of the motor velocity to reduce with the applied load is overcome by the feedback signal from the output. If the feedback signal is less than the input, the resulting error voltage will increase the motor velocity until the feedback voltage nulls the input, thereby causing the motor velocity to be proportional to the input. When a torque load is applied, the shaft decreases its velocity, causing an error signal. This error signal initiates a greater output to meet the demand of the torque load. With a large controller gain, a full motor torque can be developed with only a slight velocity error.

An acceleration servo is similar to a velocity servo except that it is used to control the acceleration rather than the velocity of its load.

Servo System Ratings

Servo systems are rated qualitatively in accordance with certain of their inherent characteristics. These characteristics are important; their names and definitions should be studied until they are second-nature to the trainee.

Static error: The angular lag between the input and the output under static conditions. A low figure is desirable.

Static error under load: The angular lag produced between the input and the output when a specific torque has been applied to the output. A low figure is desirable.

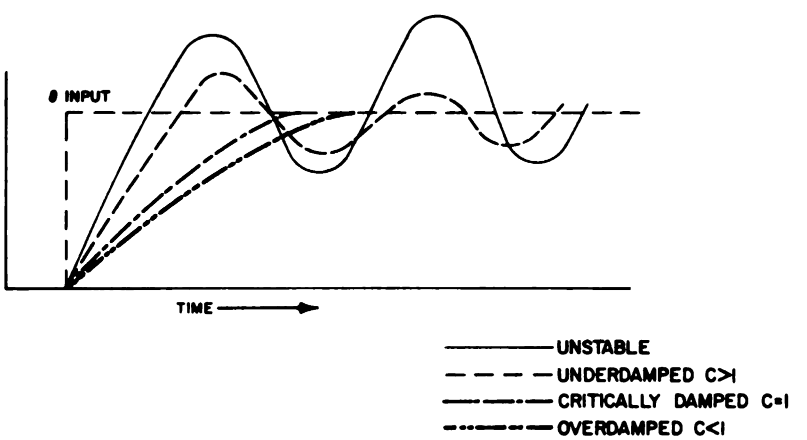
A velocity figure of merit: Obtained by dividing the velocity of the output (expressed in degrees per second) by the angular lag between the output and input (expressed in degrees) when the system is moving its load at a constant speed. This figure indicates how quickly the system responds to a constant input.

$$\frac{\text{Velocity (degrees per second)}}{\text{Error (degrees)}} = \text{Velocity error constant (units per second)}$$

Servo System Ratings (Continued)

The error signal indicates that a positional phase difference exists between the input and the output. When a positioning servo is following a steady velocity input, an additional error proportional to the velocity is developed. This error is called the velocity lag. A velocity figure of merit is used in evaluating system performance. A high figure is desirable.

Damping constant: This is related to the transient response of a servo. In most instances, some external damping factor must be added to reduce the effects of inertia. An overdamped servo is sluggish and usually responds to a change without overshooting. A slightly under-damped servo usually gives a quick response to a change with only moderate overshoot and practically no oscillation. A greatly under-damped servo will overshoot badly and oscillate for some time after a change in position has been initiated.



71. Servo Response Error-Time Curves for Damped Servo

Servo System Ratings (Continued)

To avoid hunting conditions, the servo must be damped to anticipate the null so that the motor can be braked before the desired output position is reached. To obtain maximum frequency response and minimum synchronizing time, the damping constant C is made less than 1.0 ($C < 1.0$). Where no overshoot can be tolerated, systems are critically damped ($C = 1.0$). If smoothing is necessary, C is made greater than 1.0 ($C > 1.0$).

Acceleration figure of merit: The ratio between a constant acceleration of the system (expressed in degrees per second per second) and the angular lag between the output and input (expressed in degrees). The acceleration figure of merit is obtained from:

$$\frac{\text{Acceleration (degrees per second}^2\text{)}}{\text{Error (degrees)}} = \text{Acceleration error constant (ft/sec}^2\text{)}$$

A high figure of merit indicates the ability of the system to follow on an increasing or decreasing input accurately and rapidly. When the input is changing, acceleration lag depends upon the ability of the servo to speed up quickly, especially when the output is required to keep up with the input.

Summary

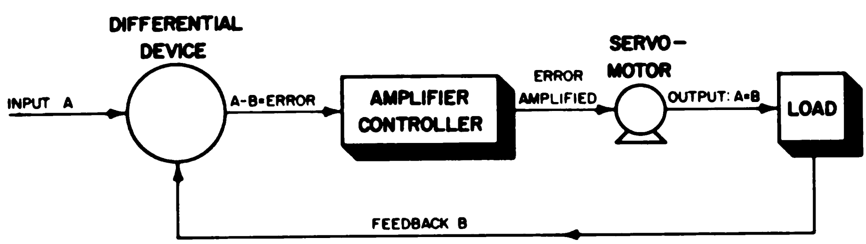
This topic discusses what a servo is, the function of servo components, servo terminology, classifications of servos, and servo system ratings.

Summary (Continued)

Basically, a servo is an automatic control device. The basic principle of servo operation is: the input signal does not drive the output; and the driving signal is provided by the difference between the input and output signals. There are two types of servo systems: the open loop and the closed loop. The major difference between these two systems is:

> In the open loop system, the input does not depend upon the output nor is the input affected by the output.
>
> The closed loop system incorporates a feedback which causes the output to be controlled by the difference between the input and the resulting output.

To augment the trainee's comprehension of closed loop systems, a slightly different diagram is shown for review and summary.



72. Control of Output by Difference Between Input and Resulting Output

In this block diagram, the output or the load is being driven by the difference or error signal, which is fed to the amplifier between the input and the output. The feedback of the output is subtracted from the input to solve for A-B=0, where A is the input signal and B is the feedback. When B does not equal A, the difference is the error signal which drives the output until input and output are equal.

Summary (Continued)

Functionally, a servo compares the input and output positions and converts the difference in position into an error signal by utilizing the components shown in the block diagram. These components are:

1. an input, which could be in the form of a voltage from a synchro transmitter, a voltage from a potentiomenter, or a mechanical input to a differential;
2. an error detecting device, such as a differential synchro, a synchro control transformer, or a controller and mechanical differential;
3. a servoamplifier, which amplifies the signal from the error detector or controller;
4. a servomotor, which receives its power from the amplifier;
5. a load, which may be a radar antenna, a gun turret, a ship rudder, a sonar transducer, etc., and
6. a feedback signal, which is provided by the load for comparison with the input signal at the differential device.

The closed loop is formed by the input signal going through the various components to the load and the automatic feedback of information to the differential device.

The trainee should be able to recognize and define the following servo terms without hesitation.

Open loop: when servo system activation depends entirely upon the input data.

Closed loop: when the servo action depends upon the difference between the input and output to incorporate feedback for automatic control.

Continuous control: the continuous operation of a servo system on its load regardless of the smallness of error.

Error signal: the corrective signal generated by the difference between the input and output.

Summary (Continued)

Servos are classified according to specific types: positioning servos, velocity servos, and acceleration servos. The positioning servo is used to position gun turrets, radar antennas, sonar transducers, fire control devices, etc. The velocity servo is used for equipment requiring a motor shaft velocity corresponding to input voltage, for example, a computer integrator. The use of acceleration servos is increasing tremendously with the increasing use of missile guidance systems where controlled acceleration is of prime importance.

A thorough understanding of servo system rating is the foundation for the understanding of servo characteristics and for the comprehension of other courses in synchro-servo systems.

Static error: the angular lag between the input and the output when the system is at rest.

Static error under load: the difference in angular lag between the input and the output member when a specific torque is applied to the output.

Velocity figure of merit: the velocity (in degrees per second) divided by the error (in degrees).

Damping constant: provides anticipation of the null so that the servomotor can be braked before the desired output position is reached.

Acceleration figure of merit: the acceleration (in degrees per second per second) divided by the error (in degrees).

TOPIC 2. SERVOAMPLIFIERS (AC)

You Are Now Going to Learn:

1. Purpose of servoamplifiers.
2. Functional operation of a simple servoamplifier.
3. Servoamplifiers used in Naval equipment.

Discussion Points for This Topic Are:

1. Characteristics of AC servoamplifiers.
2. Thyratron operation.
3. Operation of a simple servoamplifier.
4. Gain control of a servoamplifier.
5. Servoamplifiers in Naval equipment.

ASSIGNMENT:

PURPOSE:

To become familiar with servoamplifiers, the use of thyratrons, and the use of servoamplifiers.

TOPIC 2: SERVOAMPLIFIERS (AC)

Purpose of Servoamplifiers

A servomechanism must have some means of amplifying the error signal to a value large enough to control a source of power. The controlled source of power is generally an AC motor, which provides the physical power to drive the output shaft and the associated gearing.

AC servoamplifiers have several inherent characteristics that are most desirable:

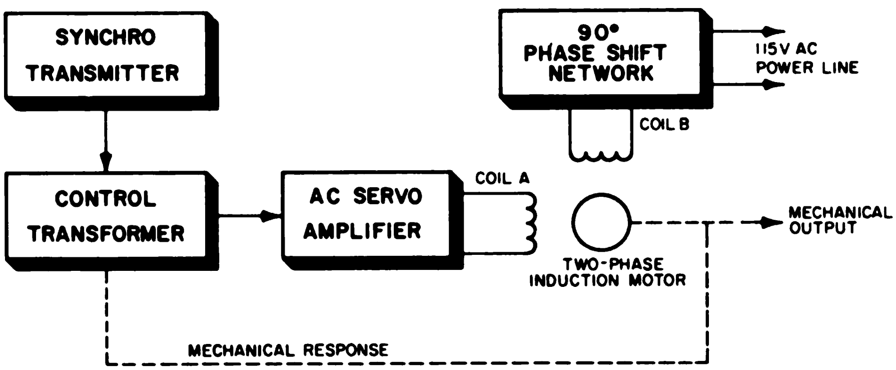
1. flat amplitude response or gain over the broad band of frequencies of interest,
2. small and fixed phase-shift of the output with respect to the input,
3. low output impedance, and low nonlinearity of amplifiers, and
4. low noise level.

Most AC servomotors have a linear torque/rpm characteristic over a wide range of voltages so that the output speed is proportional to the error voltage. The two-phase induction motor is the most widely used AC servomotor; its output torque is roughly proportional to the applied control voltage, and the direction of its output torque is determined by the polarity of the control voltage.

The two-phase induction motor employs two-phase excitation, for which approximately half the power is supplied by the AC line and the other half by the servoamplifier. The two voltages applied to the two windings are 90° apart in phase. Usually, one winding is excited with a fixed voltage; the other winding is excited by the control voltage, which is the output of the servoamplifier. The mechanical output power of this motor varies from approximately 1/1500 to 2/15 horsepower.

Purpose of Servoamplifiers (Continued)

The accompanying diagram illustrates how a two-phase induction motor is used with an AC servomechanism.



73. Servo Using a Two-Phase Induction Motor

The amplifier amplifies the error signal and sends it to Coil A of the motor. Since the magnetic fields of Coils A and B are 90° out-of-phase, the motor will rotate. The phase of the error signal determines the direction of motor rotation. The mechanical response linkage from the motor to the control transformer is a degenerative feedback that tends to reduce the error. When the error has been reduced to zero, there will be no error signal input to the servoamplifier; thus, no field in Coil A. Coil B will still have its field, generated from the AC power source, but there will be no rotation of flux, no torque produced by the motor, and no rotation of the motor shaft.

Review of Thyratron Operation. To assure complete comprehension of a detailed description of servoamplifier operation, a brief review of thyratron operation may be beneficial.

A thyratron is a three-element gas tube. It is often used as a power output tube because it can pass a great deal of current. It consists of a glass envelope containing an inert gas, a directly heated cathode, a plate, and a control grid between the cathode and plate.

Purpose of Servoamplifiers (Continued)

When the plate becomes positive with respect to the cathode, electrons are emitted by the cathode. In trying to get to the plate, the electrons bombard atoms of the inert gas, knocking electrons from the atoms. Thus, these atoms become positively charged ions that are repelled by the plate but attracted toward the grid and cathode. As they move toward the cathode and grid, the ions may gather some stray electrons being emitted from the cathode and become atoms again. Then the bombardment process will undoubtedly recur. Those ions that do not gather the stray electrons tend to form around the control grid. This causes the grid to become neutralized and lose control. The cathode, having a protective shield, is unaffected by any nearby collection of ions.

During ionization, the internal resistance of the thyratron is very low. Ionization represents an almost direct short; thus, amplification is so great that the output is generally rated in amperes instead of milliamperes. The main factor affecting current flow from the tube during ionization is the resistance of the load. The control grid permits or prevents the flow of current, but once the flow has started, the grid has no further effect. Grid control is lost because of the sheath of ions which forms on the grid structure. Varying the grid potential only makes the sheath thicker or thinner.

In the next half cycle, the plate potential goes negative, repelling the free electrons toward the grid and cathode. The sheath of positive ions around the grid accepts the electrons and atoms are re-formed. This allows the grid to become negative again.

Purpose of Servoamplifiers (Continued)

Four terms often used when describing thyratron operation are:

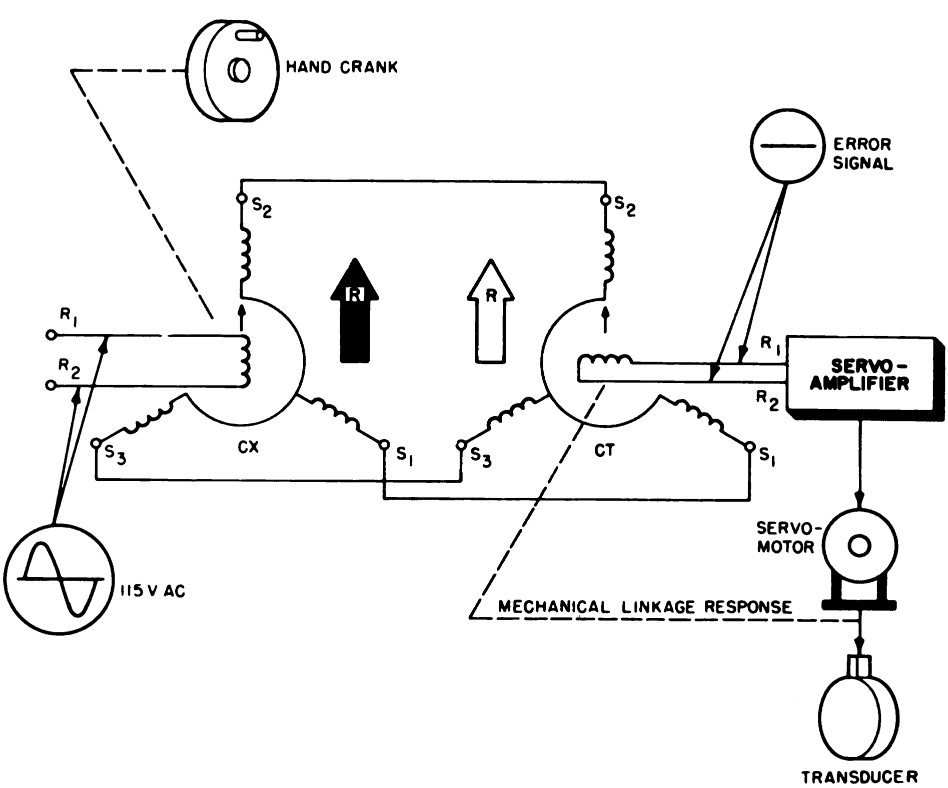
Ionization: the separation of atoms into ions.

Ionization voltage: the minimum positive potential of the plate, with respect to the cathode, that will cause ionization.

De-ionization voltage: the minimum positive potential of the plate, with respect to the cathode, that will cause ionization to cease.

Critical grid voltage: the minimum negative potential of the control grid, with respect to the cathode, that will prevent ionization with a given plate voltage. Because the control characteristics cannot be sharply defined, there is a range of critical grid voltage for each plate voltage.

Functional Operation of a Simple Servoamplifier

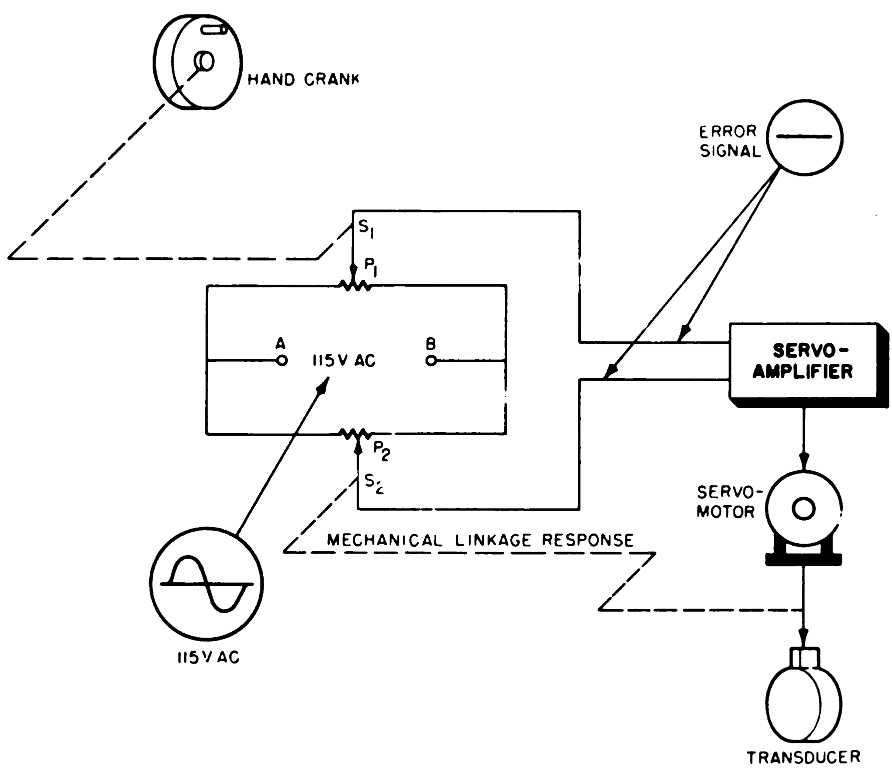


74. Typical Servomechanism Using Synchros

Functional Operation of a Simple Servoamplifier (Continued)

Error Signal Input. When an AC amplifier receives an alternating voltage as its input, an alternating voltage of the same frequency, but larger in amplitude, is developed as its output.

The input of a servoamplifier is an error voltage from either synchros or balanced potentiometers. Components within the servo-amplifier perform the gain control, phase-shifting, modulation, demodulation, and amplification necessary to enable the servo-mechanism to carry out its basic function.

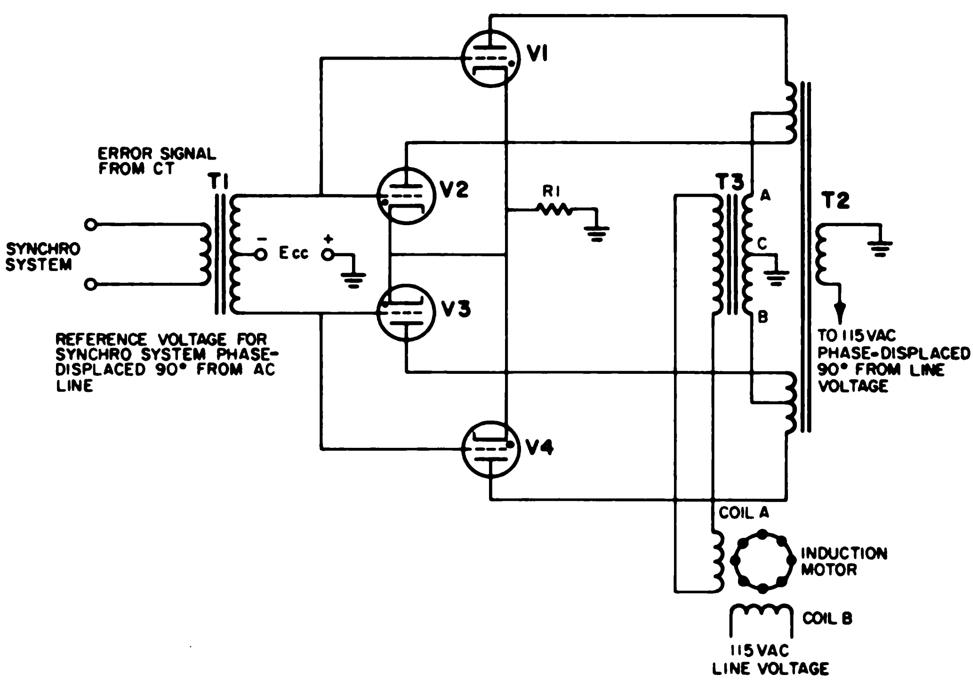


75. Typical Servomechanism Using Balanced Potentiometers

Functional Operation of a Simple Servoamplifier (Continued)

The accompanying schematic diagram of an AC servoamplifier illustrates the type of circuit used to drive a two-phase servo induction motor. Four thyratrons are used in this amplifier; two of these operate on each alternate half cycle.

The error signal from the control transformer is coupled to the grids of the thyratron tubes by transformer T1. A negative source of bias is also connected to the grids through the center tap of the secondary winding of transformer T1. This bias prevents the thyratrons from firing when there is no error signal input. Transformer T2 applies plate voltage, phase-displaced 90° from the line voltage, to the plates of all four thyratrons. The two secondary windings of T2 are arranged so that the plate voltage of V1 and V4 is in phase with the plate supply, and the plate voltage of V2 and V3 is 180° out-of-phase with the plate supply.



76. Schematic Diagram of an AC Servoamplifier

Functional Operation of a Simple Servoamplifier (Continued)

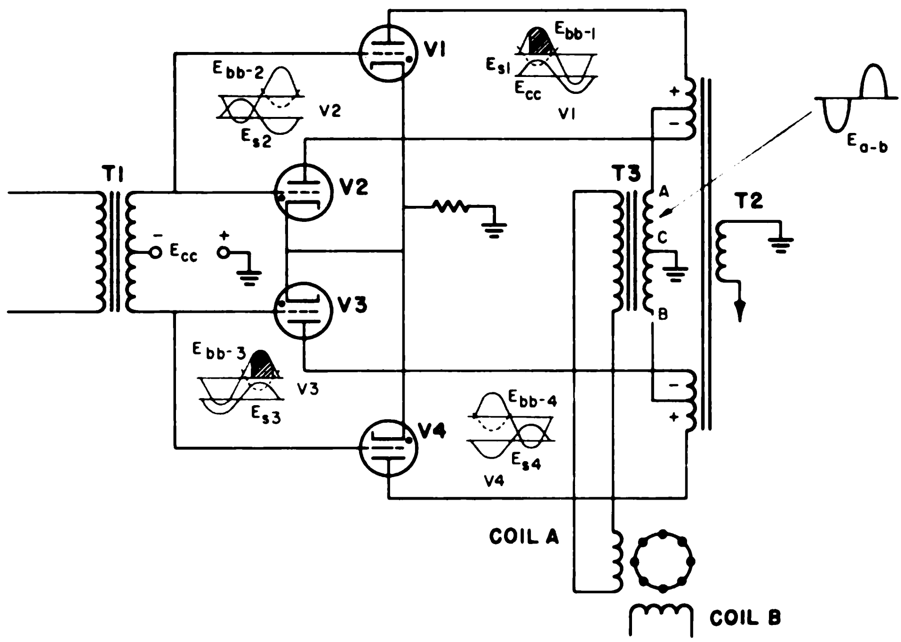
Coil A of the servomotor is energized by induced voltage in the secondary of transformer T3. The primary of T3 is supplied from the centertaps of the two secondaries of T2. This supply is phase-displaced 90° from the line voltage. Coil B of the servomotor is connected directly to the line; therefore, the magnetic fields of coils A and B will be 90° out-of-phase every time coil is energized.

With no error signal input, the thyratrons will not conduct; there will be no output signal to the servomotor; and the servomotor shaft will not rotate. If an error signal is applied, the thyratrons will conduct; and there will be an output signal that will drive the servomotor.

If an error voltage with an instantaneous positive polarity appears at the top of the T1 secondary and at the same time the V1 plate swings positive, V1 fires. V2 cannot fire because its plate is negative, and V4, having an additional negative bias, remains cut off. As long as the error voltage maintains this phase relationship, V2 and V4 cannot fire. On the first alternation, current flows in T3 from A to C. On the following alternation, both grid and plate of V3 swing positive; and V3 fires with a plate current flow from B to C in T3. Thus, V1 and V3 conduct on alternate half-cycles, causing an AC voltage to be induced in the T3 secondary. This voltage may be either in phase with the reference voltage or out-of-phase. The servomotor now turns in the ordered direction. Reversal of the error voltage phase causes V2 and V4 to become the conducting thyratrons and shifts the controlled phase 180° with respect to the reference voltage. Thus, the servomotor reverses its direction of rotation.

Functional Operation of a Simple Servoamplifier (Continued)

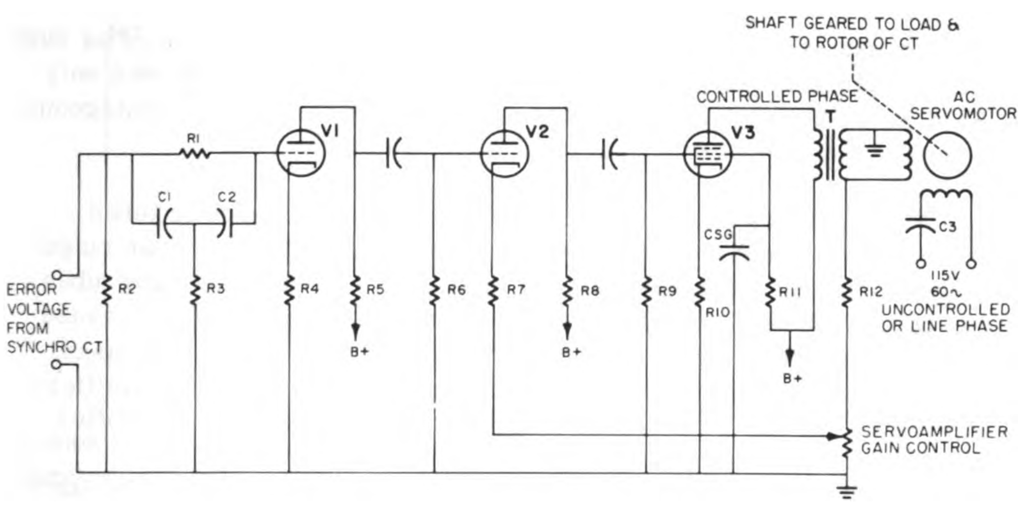
In the schematic diagram below, the illustrated waveforms show the effect of an entire cycle of the error signal input. In this situation, the action will produce clockwise rotation of the servomotor.



77. Waveforms for Clockwise Rotation of Motor

Functional Operation of a Simple Servoamplifier (Continued)

<u>Gain Control</u>. The gain of a servoamplifier is usually controlled by a potentiometer. A portion of the output voltage is picked off by the variable resistor and applied as a degenerative feedback to the cathode of one of the stages of amplification. The amount of feedback picked off determines the amount of amplification or gain of the output signal. The accompanying illustration shows one example of this type of gain control. The ideal setting for the potentiometer is one that allows the highest servoamplifier output without causing the servomotor to oscillate.



78. Potentiometer Gain Control in Servoamplifier

Functional Operation of a Simple Servoamplifier (Continued)

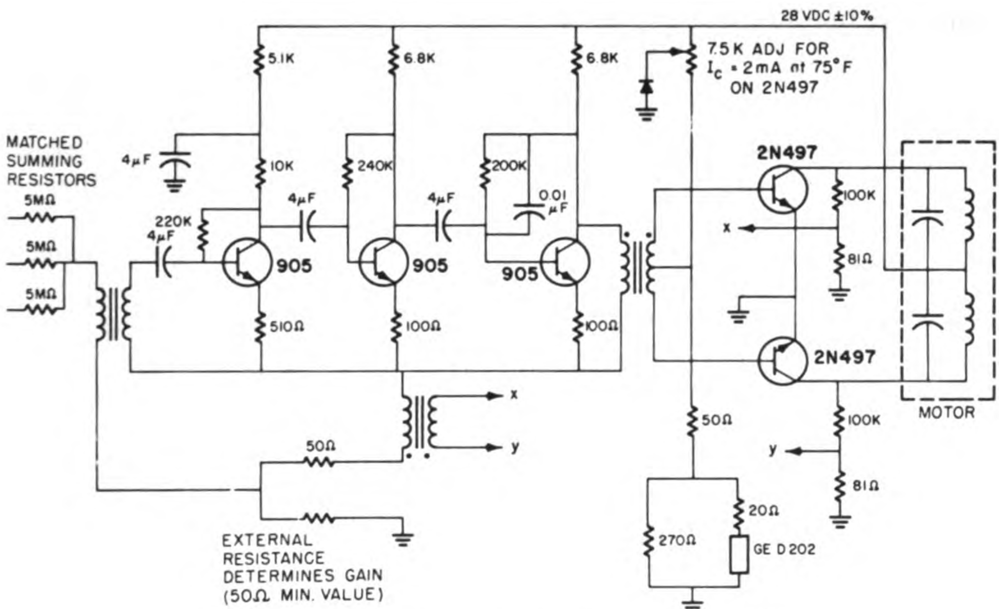
Output Amplification. The output stage of a servoamplifier drives an induction servomotor that normally presents an inductive load impedance to the amplifier. Motor impedance is a function of motor speed, the inductive component changing with motor speed. The back EMF developed with rotation is responsible for the major portion of the impedance change. By placing a capacitor in parallel with the load, the load can be tuned to resonance at the operating frequency, thus presenting a constant resistive load for the amplifier. A constant resistive load will effect an increase in the efficiency of the power output stage.

Vacuum-tube servoamplifiers may have either single ended or push-pull outputs. Single ended outputs, however, are generally used only when the output power is less than one watt and when it is advantageous to keep the number of vacuum tubes to a minimum.

Vacuum tubes used in output stages may be beam-power tubes, pentodes, or triodes. The largest vacuum tube practical for an output stage is the 6L6. If more power is required, transmitting-type tubes can be used; however, these are not ordinarily recommended because of their dangerously high plate voltage requirements. In such cases, other output means such as magnetic amplifiers or rotating amplifiers are used; and the vacuum-tube amplifier functions as a preamplifier.

With the development of reliable transistors and the rapid advance in transistor technology, application of transistors to military electronic equipments, such as radar, sonar, and computers, is becoming a common practice. A typical transistorized servoamplifier can be used in many servo systems requiring a size 11 or 15 servomotor with a power output of 3 watts.

Functional Operation of a Simple Servoamplifier (Continued)

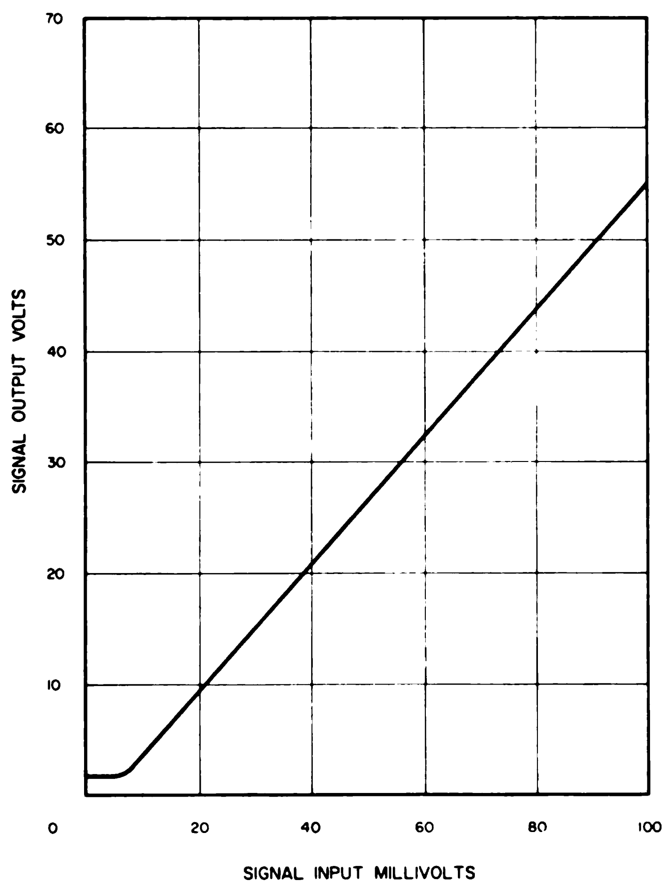


79. Typical Transistorized Servoamplifier

The illustrated amplifier uses three type-905 transistors in three almost identical amplifiers. The output from this amplifier is transformer-coupled to a pair of 2N497 transistors in push-pull; these make up the power output stage. The output drives the motor load directly with no output transformer required. Feedback voltage from the collectors of the output transistors is added to the input signal. In this particular amplifier, three, matched, summing resistors are provided to add three signals at the input. Base-current bias is supplied to the first three transistors with 200 kilohms (or 240 kilohms) resistors from collector to base. The servomotor is driven directly from the collectors of the output transistors.

Functional Operation of a Simple Servoamplifier (Continued)

The accompanying graph shows the input-output ratio for transistorized servoamplifiers.



80. Input-Output Ratio for a Transistorized Servoamplifier

SERVOAMPLIFIERS (AC)

Servoamplifiers Used in Naval Equipment

Servoamplifiers are found in fire control systems, radar systems, sonar systems, and computers. In fire control equipment, the operation of computers and the training and elevation of guns, missile launchers, and radar antennas depend upon servos. The PPI radar repeater uses a position-sensing servo system to synchronize the rotation of the sweep deflection coil with the master antenna. Sonar equipments employ servos to train the transducer.

Summary

The purpose of an AC servoamplifier is to receive an input signal, to compare this signal to the present load position, to develop and amplify the error signal, and to apply the amplified error signal to drive a servomotor. The stator of the servomotor, usually a two-phase induction motor, consists of two windings that are 90° out-of-phase. One winding is the reference winding, and its voltage is supplied from the line. The other winding receives the error voltage output from the servoamplifier.

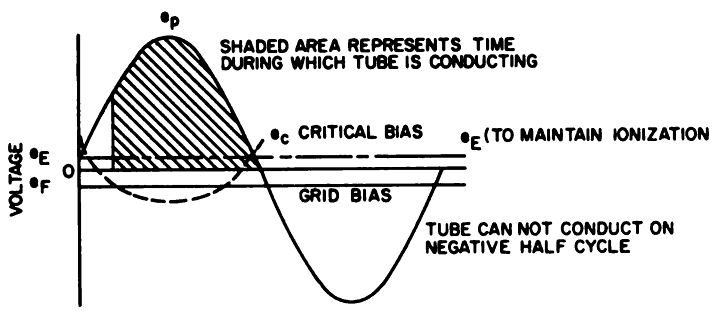
The two-phase induction servomotor has many desirable qualities, the most important of which is a linear torque/rpm ratio over a large range of voltages so that the output speed is proportional to the error signal. In addition, this type of servomotor may be used when power requirements vary from approximately 1/2 to 100 watts.

The overall gain of a servoamplifier is deliberately high in order to reduce velocity and acceleration errors and to increase the resonant or natural frequency response. Response to rapidly changing inputs is desirable; however, too much gain will produce servomotor oscillations.

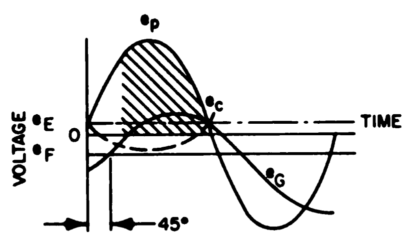
The most common AC servoamplifiers used in naval equipments are those employing thyratrons, vacuum tubes, or transistors.

Summary (Continued)

The thyratron is a gas-filled tube used to control the output current continuously from zero to maximum value. The magnitude of grid voltage that must be applied for plate current to flow for a particular plate-voltage waveform can be determined from the critical grid voltage for each value of plate voltage. Thus, the firing point of a thyratron can be controlled by the grid bias or sine wave voltage on the grid. Tube conduction cannot be stopped by grid voltage; plate voltage must drop below the de-ionizing potential in order to stop conduction.



GRID BIAS CONTROL
(a)



SINE WAVE CONTROL
(b)

81. Thyratron Conduction Control

Transistor amplifiers are extremely desirable where small servomotors (size 11 or 15 with power output of 3 watts) are used. Where weight and physical size are critical, transistor amplifiers are especially useful because of their high reliability.

STUDENT NOTES

TOPIC 3. SERVOMOTORS (AC)

You Are Now Going to Learn:

1. Function of the servomotor.
2. Two phase motor in servo system.
3. Circuit variations for two-phase operation.
4. Phasing problems for correct rotation.

Discussion Points for This Topic Are:

1. Operation of the two phase servomotor.
2. Drag-cup servomotor.
3. Phasing problems.

ASSIGNMENT:

NAVPERS 10086-A, pages 384-385.

PURPOSE:

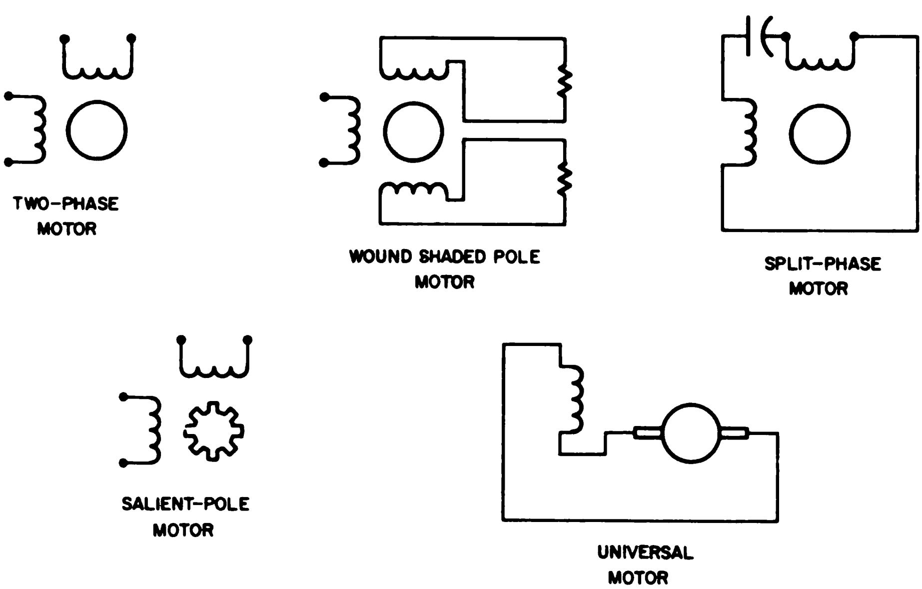
To become familiar with servomotors, the theory of servomotors, and phasing problems.

TOPIC 3. SERVOMOTORS (AC)

Function of the Servomotor

Most of the smaller motors used in servomechanisms are the two-phase induction type and are used where low power and low speed applications are required. Radar automatic tracking circuits use AC servomotors to rotate synchro differentials and synchro transmitters. Search radar and target designation systems use AC servomotors to rotate magnetic deflection coils for the cathode ray tubes. Computers and other instruments also employ two phase servomotors extensively. The mechanical output power of these motors varies from about 1/2 watt to 100 watts. Larger AC motors are too inefficient; and, if constructed with the desired torque-speed curves for servo use, they are difficult to cool.

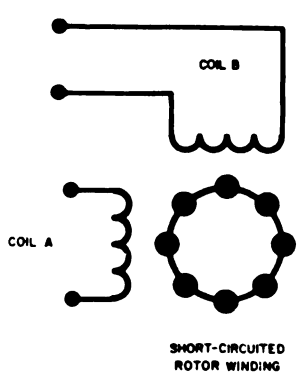
In this publication, the primary emphasis is placed on the two-phase, induction-type motor; however, the accompanying schematic diagrams illustrate many types of AC motors that may be employed in servo systems.



82. Schematic Diagrams of Typical AC Motors

Two Phase Motor in Servo System

The two-phase induction motor receives approximately half its power from the AC line; the other half is supplied by the output of the servoamplifier. The voltages applied to the two windings are 90° out-of-phase. Normally, one winding is excited with a fixed voltage; the other winding is excited by the control voltage, which is the output of the servoamplifier. The stator of the motor consists of two similar windings positioned at right angles to each other. The rotor may be wound with short-circuited turns of wire, or it may be the squirrel-cage rotor type. The squirrel-cage rotor is the more common type. It is made of heavy conducting bars which are set into armature slots, the bars being shorted by conducting rings at the ends. Two stator windings, physically placed 90° apart, receive AC voltages. Current from these 90° out-of-phase voltages generates a rotating magnetic field, which induces current in the rotor by transformer action (mutual inductance). This current generates a magnetic field in the rotor, which is displaced 90° from the magnetic field in the stator. The interaction of the two magnetic fields causes the armature to rotate.

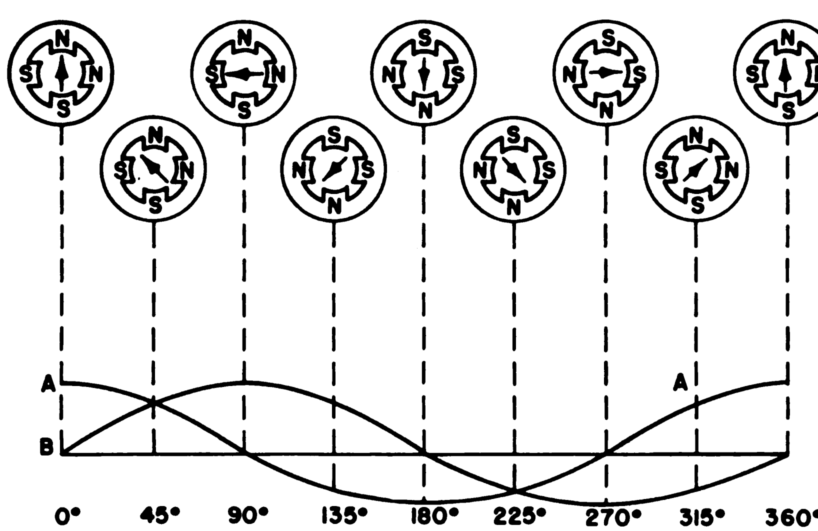


83. Stator Windings 90° Apart

Two Phase Motor in Servo System (Continued)

If the voltages applied to coils A and B are 90° out-of-phase, their currents will also be 90° out-of-phase; thus, their magnetic fields will be displaced 90°. At every instant during each cycle the two magnetic fields will add, producing one resultant field that will rotate one revolution for each cycle of AC.

The accompanying diagram illustrates the two magnetic fields which are displaced 90° in phase. At the 0° point (corresponding to position 1), the magnetic field in coil B is zero, and the magnetic field in coil A is maximum. The resultant magnetic field will, therefore, point in the direction of the coil A axis. At the 45° point (corresponding to position 2), the resultant magnetic field will point midway between coils A and B because the magnetic fields in coils A and B are equal. At the 90° point, the magnetic field in coil A is zero; and the magnetic field in coil B is maximum. The resultant magnetic field will now point in the direction of the coil B axis. Thus, the resultant magnetic field must have rotated through 90° in order to get from position 1 to position 3. At the 135° point (corresponding to position 4), the magnetic fields are again equal, but the magnetic field in coil A has reversed its direction. The resultant magnetic field, therefore, lies midway between the magnetic field axes and points in the direction shown.

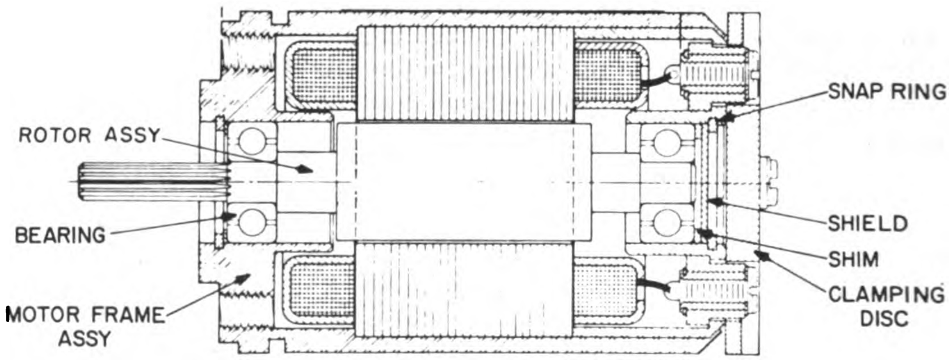


84. Magnetic Fields Displaced 90° In Phase

Two Phase Motor in Servo System (Continued)

At the 180° point (corresponding to position 5), the magnetic field in coil B is zero, and the magnetic field in coil A is maximum. The resultant magnetic field will, therefore, lie in the direction of the coil A axis and will point down as shown.

Squirrel-cage motors operate in much the same manner as motors with shorted rotor windings. As the magnetic field rotates, it cuts through the short-circuited conductors on the armature and causes current to flow in them. A force is exerted on the conductors in the same direction as the rotating magnetic field; hence, the motor armature starts rotating. To reverse the direction of rotation, the current flowing in one of the coils must be reversed. Thus, rotation of the magnetic field and the rotor will be in the opposite direction. The rotational speed of the motor can be changed by varying the strength of one of the magnetic fields.

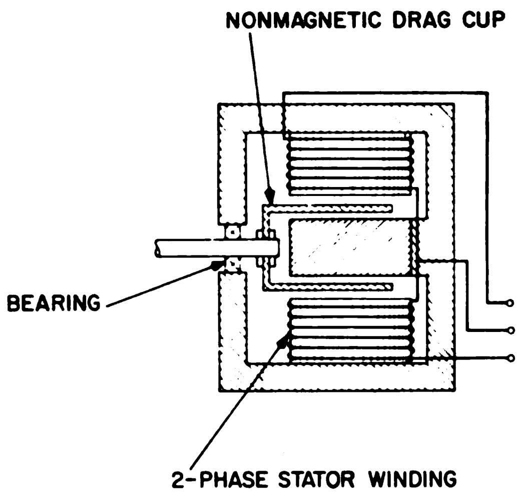


85. Typical Squirrel Cage Servomotor

Another type of AC servomotor found in instrument-servo application is the drag-cup servomotor. This motor is designed for very low power applications. The drag-cup motor is similar to the drag-cup generator. Its cup is constructed of copper, aluminum, or an alloy. A drag-cup motor of the same size and weight as a squirrel-cage motor generally has lower torque; the inertia of the drag-cup motor is less because only a light cup is rotated.

Two Phase Motor in Servo System (Continued)

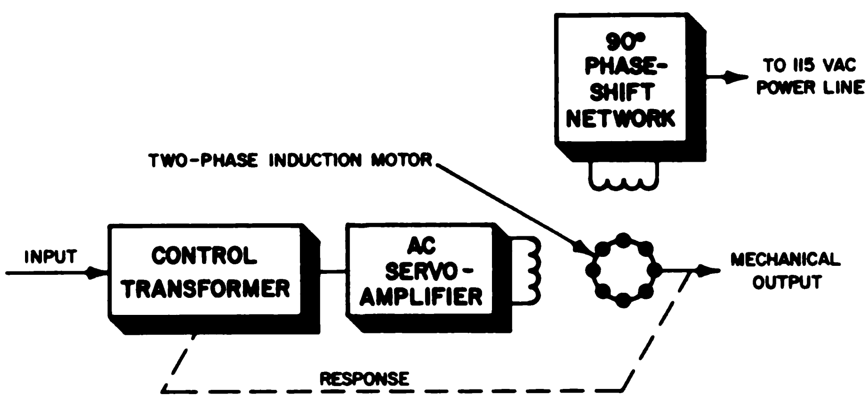
For very low power instrument applications, a drag-cup servomotor can be operated without an output transformer. The constant current from the B+ supply during the quiescent condition of the output tube produces a magnetic drag on the motor and helps to stabilize the servomechanism.



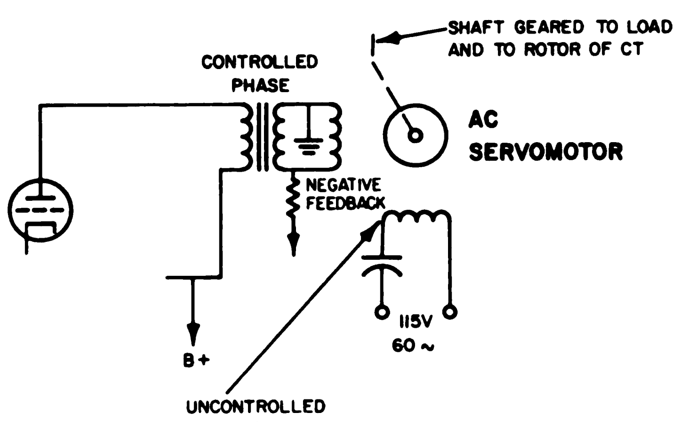
86. Typical Drag-Cup Servomotor

Circuit Variations for Two Phase Operation

The block diagram shows a typical use of a two-phase induction servomotor in a servomechanism. There are two ways in which the circuit can be varied for two-phase motor operation. The typical circuit has a capacitor in series with the uncontrolled phase or reference winding of the motor. The line voltage supplying excitation to this winding is phase-shifted 90° by the capacitor. The voltage supply to the control transformer and servoamplifier is also from the line but is not phase-shifted; thus, the voltage output of the servoamplifier will be 90° out-of-phase with the voltage in the reference winding.



87. Block Diagram of Typical Circuit for Operation of a Two-Phase Induction Servomotor



88. Use of Capacitor in Uncontrolled Phase Winding

Circuit Variations for Two Phase Operation (Continued)

Another circuit variation for two-phase motor operation is to remove the capacitor from the reference winding and to phase-shift the supply to the synchros and servoamplifier. This variation is the reverse of the one described earlier but produces the same results from the motor.

Phasing Problems for Correct Rotation

One of the problems encountered in servo design is phase-shift control. If the system is to operate satisfactorily, the error detectors and motors must be supplied with voltages of the proper phase relation.

If balanced potentiometers are used as error detectors, voltages applied to the two potentiometers must have the same phase so that the actuating signal voltage will have no quadrature component. If double speed synchros are used, the stick-off voltage must be in phase with the output of the coarse synchro so that no quadrature voltage can be developed. This prevents false synchronization 180° out-of-phase. If a phase-sensitive detector is used in the servomechanism, the phase of the supply voltage must be the same as the phase of the signal voltage.

Summary

In servomechanisms, AC servomotors have a wide use in low-power applications. The two phase motor receives half of its power from the reference voltage; the other half of its power is supplied by the servoamplifier error signal. The two voltage supplies are 90° out-of-phase with each other. Speed of the two-phase induction servomotor can be varied, within limits, by varying the voltage applied to one stator winding. The direction of rotation can be changed by reversing the phase of the voltage applied to one winding.

Phase-shifting to maintain the 90° phase relation in the two phase servomotor can be done in the fixed amplitude motor winding or in the input circuit of the servoamplifier that feeds the variable phase and amplitude winding.

Summary (Continued)

Error detectors and servomotors must be supplied with voltages of the proper phase. Potentiometer error detectors require voltages of the same phase; otherwise, quadrature voltages may develop. If double speed synchros are used, the stick-off voltage must be in phase with the output of the coarse synchro so that no quadrature voltages can be generated to cause false synchronization. When using phase-sensitive detectors, the supply voltage phase must be the same as the phase of the signal voltage.

STUDENT NOTES

TOPIC 4. RESPONSE IN SERVO SYSTEMS

You Are Now Going to Learn:

1. Function of an error detector in a servo system.
2. Control transformer error detector.
3. Balanced potentiometer error detector.
4. Closed-loop control system.
5. Nulling the error.
6. Mechanical response.

Discussion Points for This Topic Are:

1. The use of control transformers and balanced potentiometers as error detectors.
2. The use of the closed-loop control system.
3. The relationship between nulling the error and mechanical response.

ASSIGNMENT:

OP 1303 (First Revision), pages 48-49.

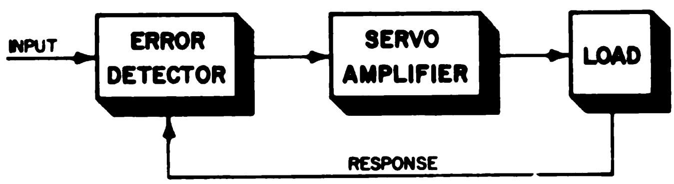
PURPOSE:

To become familiar with the various methods of error detection and the purpose of mechanical response.

TOPIC 4. RESPONSE IN SERVO SYSTEMS

Function of an Error Detector in a Servo System

A servo system will operate only when there is an error present between the input and output shafts; therefore, an error-measuring device is a most important part of the system. The error-measuring device receives the position order from the input shaft and the actual position data from the output shaft. The error detector compares the two sets of data and develops an error signal which is representative of the difference between the two.



89. Error Detector in Servo System

Functionally, the error detector must be able to:

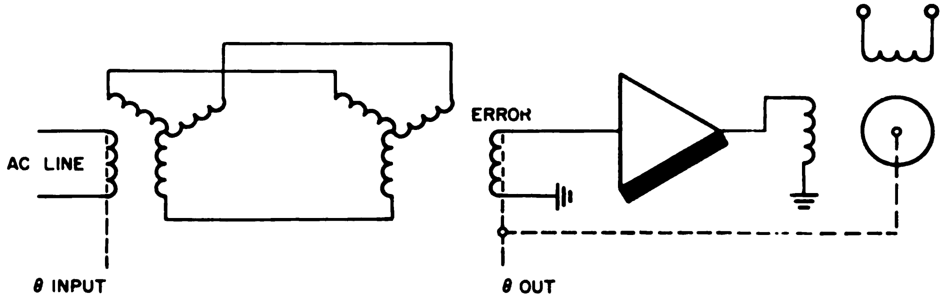
1. evaluate the existing condition,
2. accept an order and define the desired result,
3. compare the desired result with the existing condition and determine the error, and
4. issue a correcting order determined from the error.

Therefore, the error detector measures the difference between what the load is doing and what the load is ordered to do. This difference is translated into an error signal that the amplifier converts to a usable signal, thereby driving the load in the direction necessary to null the error signal. When this signal is nulled, the servo stops driving. Thus, the servo has performed its function; the original input order has been accomplished.

There are several servo system components that can be used as error detectors. Some examples of these are synchro control transformers, potentiometers, mechanical differentials, thermometers, and pneumatic and hydraulic devices. This course will emphasize the most common types of error detectors encountered in shipboard sonar, radar, and fire control systems: the control transformer and the balanced potentiometer.

Control Transformer Error Detector

The synchro control transformer is the most important component of the synchro-servo system. The CT is designed to provide an AC voltage from its rotor terminals; the magnitude and phase of this voltage depends upon the rotor position and the signal applied to its three stator windings.



90. Use of Typical Control Transformer as Error Detector

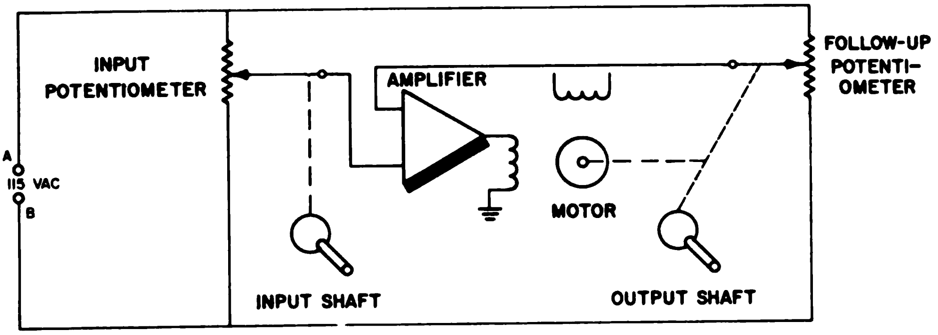
A control transmitter is used to change shaft motion into voltage with unlimited angular resolution and rotation. The servomotor drives the load of the servo system and, at the same time, through the response gearing, drives the rotor of the control transformer into correspondence with the rotor of the control transmitter. The voltage output of the control transformer is then at null. In this case, the control transformer acts as an error detector.

The amplitude of the error signal depends upon the angular difference between the control transmitter shaft and the CT shaft; the phase of the error signal depends upon the direction of CT shaft rotation. Therefore, when the CX rotor shaft is rotated clockwise, the error signal will be in phase with the reference voltage applied to the CX rotor. When the CX rotor shaft is rotated counterclockwise, the error signal will be out-of-phase with the reference voltage.

Balanced Potentiometer Error Detector

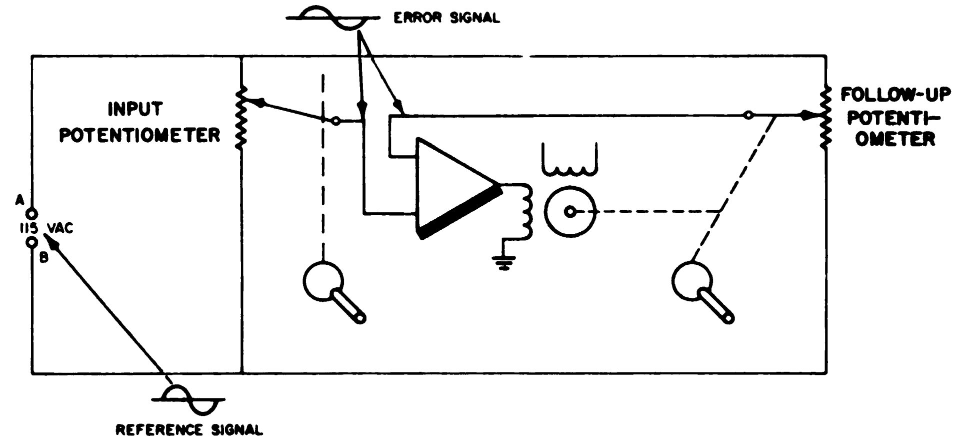
The balanced potentiometer is widely used as an error detector in positioning-type servomechanisms. Basically, balanced potentiometers perform the same error-detecting task as control transformers. The input and feedback signals are subtracted in the error detector. The amplified error signal produces the torque in the motor which drives the load to the desired position.

In the accompanying illustration, the wiper arms of the two balanced potentiometers are centered; the voltages between the sliding arms are zero. When the input shaft is rotated, the arm of the input potentiometer will move off center; and a voltage difference will develop between the input and the followup potentiometer. The amplitude of this difference voltage will depend on how far the input potentiometer shaft has been moved in relation to the position of the followup potentiometer shaft.



91. Typical Positioning Servo With Balanced Potentiometers

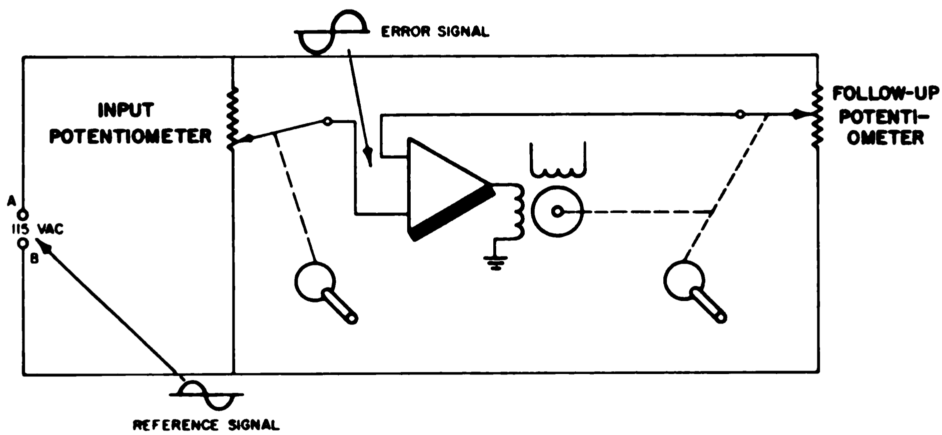
Balanced Potentiometer Error Detector (Continued)



92. Typical Positioning Servo, With Potentiometers Not Balanced, Producing Clockwise Rotation

The phase of this voltage difference will depend upon the direction in which the input potentiometer has been moved in relation to the followup potentiometer. When the input potentiometer wiper arm is moved above the wiper arm of the followup potentiometer, it is closer to terminal A of the input reference voltage; hence, the voltage difference will be in phase with the voltage between the input terminals A and B. Conversely, when the input potentiometer wiper arm is moved down, or below the followup wiper arm, it will be closer to the B terminal of the reference input terminal. Therefore, the voltage difference will be out-of-phase with the voltage between input terminals A and B.

Balanced Potentiometer Error Detector (Continued)



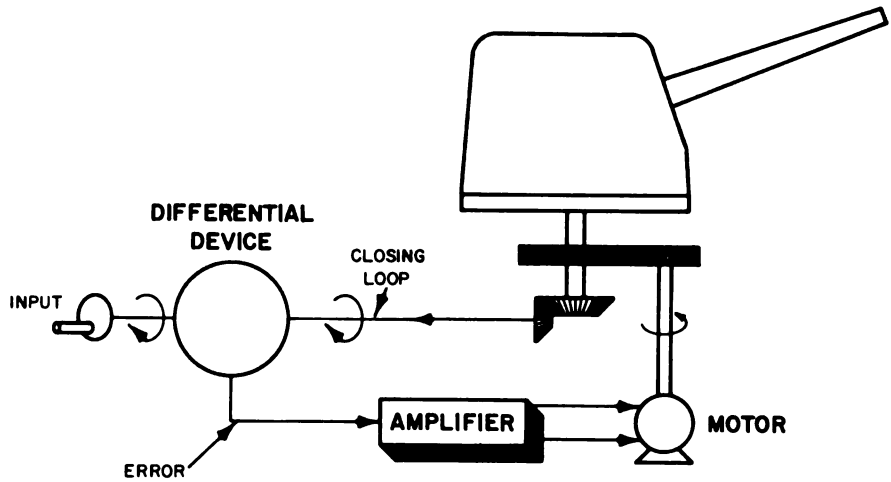
93. Typical Positioning Servo, With Potentiometers Not Balanced, Producing Counterclockwise Rotation

This voltage difference developed across the input potentiometer and the followup potentiometer is the error signal. The amplitude of the error signal is determined by the displacement of these two potentiometers from each other. The phase of the error signal in relation to the reference voltage indicates in what direction the shaft will rotate.

Closed-Loop Control System

A closed-loop control system is a system in which the output is controlled by the difference between the input and the output. An open-loop control system is a system whose input is not affected by its output; there is no feedback or response. Only closed-loop control systems will be discussed here.

Closed-Loop Control System (Continued)



94. Simplified Closed-Loop Control System

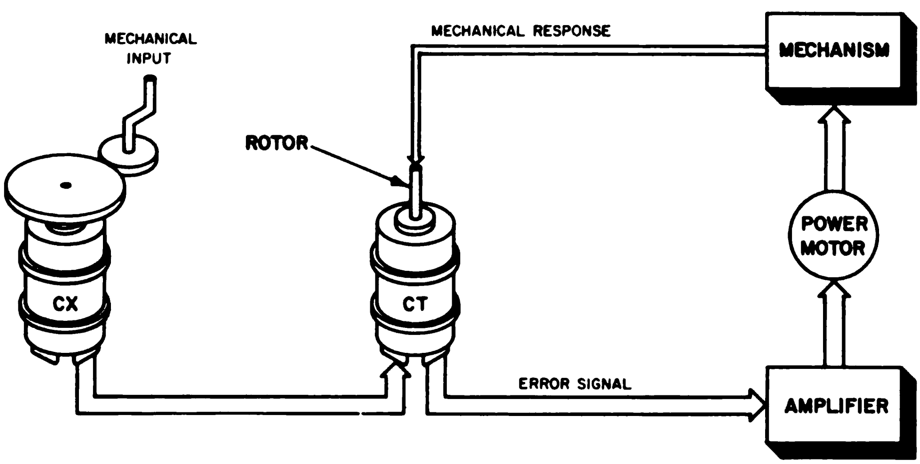
In the illustrated example of a closed loop system, a turret is connected to a motor through a system of gears. The turret is also mechanically linked to a differential device. A positioning input signal provided by the handwheel is also received at the differential device. The output signal of the differential is proportional to the error between the positions of the handwheel and the turret. This output signal actuates the amplifier which, in turn, actuates the servomotor which drives the turret to the desired position. The closing loop is that linkage between the turret and the differential device which tends to reduce the error signal to zero.

Nulling the Error

The error signal is the difference between the input and output signals. When the input or reference signal is out-of-phase with the error signal, the load will be driven in a direction determined by the phase relationship between these two signals. When the load reaches the desired position, the amplitude of the error signal will drop to zero. The reference and error signals null each other; the load ceases to move; and the servo is in equilibrium.

Mechanical Response

The accompanying diagram illustrates how mechanical response is used in a positioning-type synchro-servomechanism. An output error voltage is provided by the control transformer. The error voltage is fed to the amplifier which, in turn, provides the power necessary to drive the load. While the servomotor is rotating the load, it is also turning the CT rotor through mechanical linkage. This linkage is known as the response. The response rotates the CT rotor so that the rotors of the CX and the CT are again in correspondence. At this time, the error voltage will be nulled; and the servo system will cease to operate. The great advantage of this system is that the instant the shaft of the synchro transmitter is rotated even the slightest amount, a small error signal develops and is converted immediately into sufficient power to drive the load.



95. Mechanical Response in a Positioning Synchro-Servomechanism

RESPONSE IN SERVO SYSTEMS

Summary

The function of the error detector is to:

1. evaluate the existing positions,
2. accept an order and define the desired results,
3. compare the desired result with the existing conditions and determine the error, and
4. issue a correcting order based on the error.

Several types of error detectors are used in servos. The two most common types used on shipboard equipment are the synchro control transformer and the balanced potentiometer.

The control transformer is designed to supply an AC voltage from its rotor, the amplitude and phase of which depend upon the rotor position and the signal induced to its stator windings. The response drives the rotor of the CT until the error voltage is nulled. Thus, the error is corrected; the servo stops driving; and the load is in the ordered position.

Balanced potentiometers perform the same error-detection function as synchro control transformers. When the wiper arm of the input potentiometer is moved to a position different from that of the followup potentiometer, an error voltage is generated. The amplitude and phase of this error voltage depend upon the displacement between the wiper arms of the input and the followup potentiometers. The phase of the error signal, in relation to the reference voltage, determines the direction or servomotor rotation.

In a closed loop system, the position of the output shaft is controlled by the difference or error between the positions of the input and output shafts. The closing loop is the response, which may be a mechanical linkage, a gear train system, or an electromechanical device between the output load and the differential device. Thus, mechanical response is the linkage between the load and the error detector. The purpose of the mechanical response is to null the error signal. When this occurs, the servomotor stops rotating because the load is in the desired position; the servomechanism is at rest.

STUDENT NOTES

TOPIC 5. ANTIHUNT IN SERVO SYSTEMS

You Are Now Going to Learn:

1. Causes of oscillation.
2. Undesirable effects of oscillation.
3. Elimination of hunting and oscillation.

Discussion Points for This Topic Are:

1. Inertia, overdrive, and time delay.
2. The importance of preventing oscillation.
3. The use of feedback to eliminate oscillation.
4. Other methods for eliminating oscillation.

ASSIGNMENT:

PURPOSE:

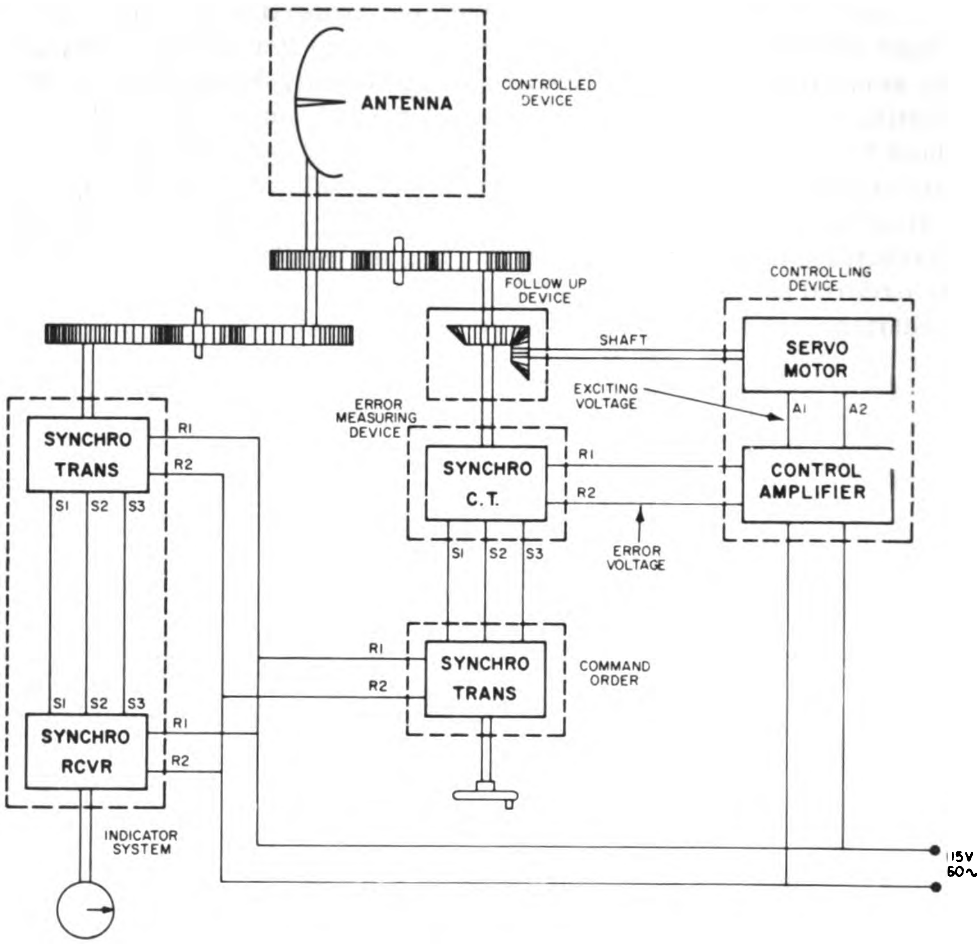
To become familiar with the causes, effects, and methods of eliminating oscillation.

TOPIC 5. ANTIHUNT IN SERVO SYSTEMS

Causes of Oscillation

Servomechanisms have some inherent properties that are undesirable. These are inertia, overdrive or overshoot, and time delay. They cause the servo to hunt, thereby destroying the stability of the servo system. Hunting is that property of the servo loop which causes the load to overshoot its ordered position and reverse its direction, and then to repeat this action, developing a succession of reversals of the motor torque and output load. Antihunt devices are used to eliminate these undesirable characteristics by preventing the hunting or oscillating of the load about its ordered position. Antihunt devices may be either mechanical or electrical and usually employ some form of feedback.

Causes of Oscillation (Continued)



96. Block Diagram of Azimuth-Positioning Servo

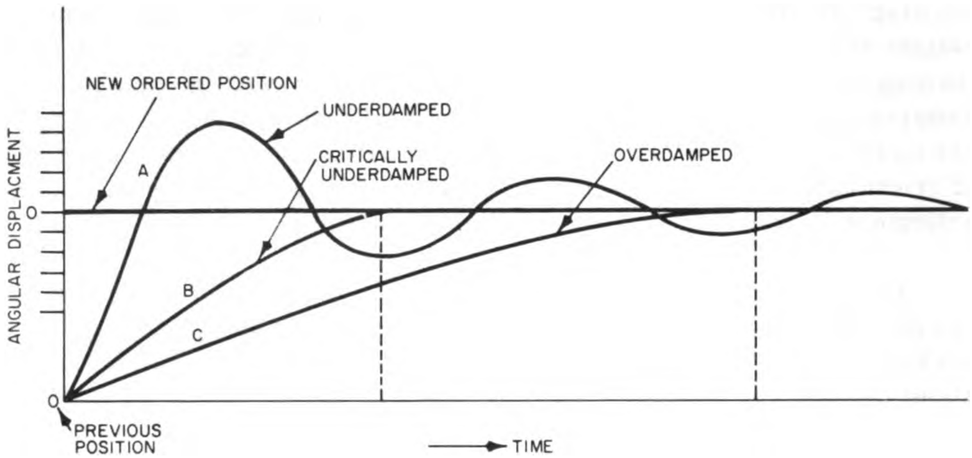
The accompanying block diagram of an azimuth-positioning servo for a radar antenna illustrates a position order that is transmitted by means of a handwheel. If the system is at rest and the handwheel is suddenly rotated, the servomotor will turn the antenna to its new desired position. When the antenna reaches its ordered position, the error signal is nulled; however, without an antihunt device, the momentum or inertia of the antenna may carry it past its ordered position. This overshooting effect

Causes of Oscillation (Continued)

develops an error voltage of opposite polarity in the CT. This voltage causes the motor to stop and then rotate in the other direction, thereby turning the antenna in the opposite direction but toward the original ordered position. Again the antenna may overshoot. The CT will again act in the opposite direction to properly position the antenna. Because of frictional losses, the oscillations will decrease in amplitude, and the antenna will finally come to a stop in its ordered position.

There is some time delay in the controlling device of a positioning servo. With this delay and with the use of a high gain amplifier, the oscillations may be strong enough to cause continuous antenna hunting about the ordered position. Such oscillations in the servomechanism are really analogous to a vacuum-tube oscillator, where the losses are counteracted by positive or regenerative feedback.

Causes of Oscillation (Continued)

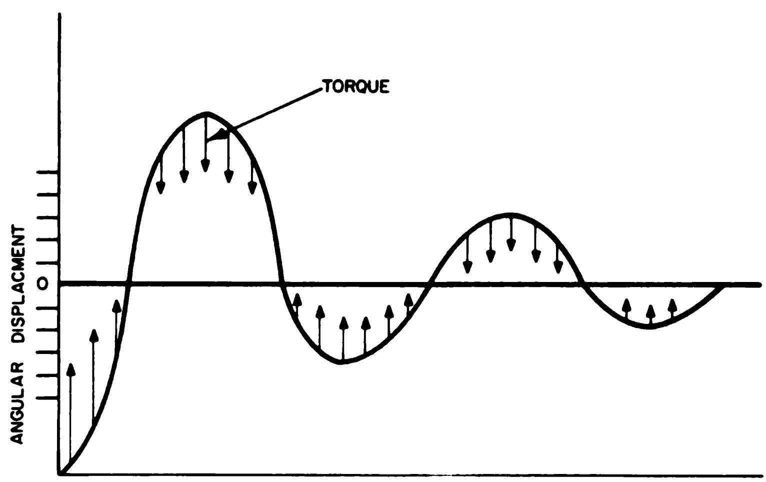


97. Servo System Damping When Position Order is Suddenly Changed

If no time delay were to exist, the graphic curves above would illustrate the response of a servo system with the application of three different values of damping. Again, if no time delay were present, the oscillations or hunting would be damped out in each of the three damping situations. There is, however, a time difference required for the load to reach the ordered position, the point at which the error voltage is nulled. Curve A represents a servo operating in an underdamped condition in which the overshoot is quite large, but the oscillation is finally damped. Curve C shows a servo overdamped. The load is slowed more than the required amount to prevent overshoot; hence, the speed of response of the system is markedly reduced, and a longer time is required to reduce the error voltage to zero. Curve B illustrates a system which is critically damped. This value of applied damping is the smallest amount which will eliminate overshoot; hence, the error voltage reaches zero in the shortest possible time and is held at that value.

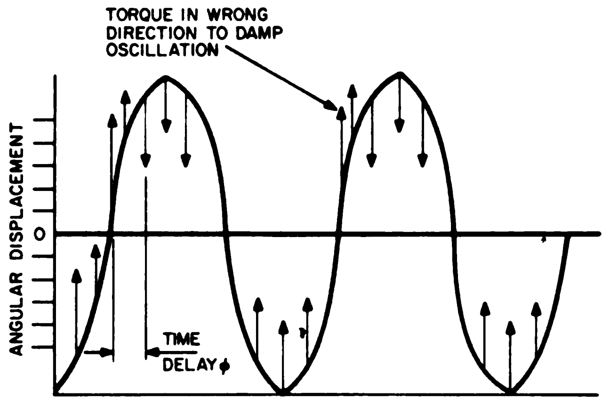
Causes of Oscillation (Continued)

The time delay in the controlling device is the factor which may be responsible for increasing output shaft oscillations and continued hunting. This undesirable situation exists when a delay is present between the time an error appears and the time a torque is applied to correct that error. In Curve A, the assumption has been made that no time delay exists in the controller; hence, the torque is proportional to the present error. Every time the load slews past its ordered position, a reverse torque is immediately applied to swing the load back to the desired position. There is no positive feedback adjustment for frictional losses, and hunting is finally damped out. In the following two illustrations, the relative size of each arrow indicates that the developed torque is proportional to the angular displacement.



98. Damping Action When Torque is Proportional to Present Error

Causes of Oscillation (Continued)



99. Continuous Hunting When Torque is Proportional to Past Error

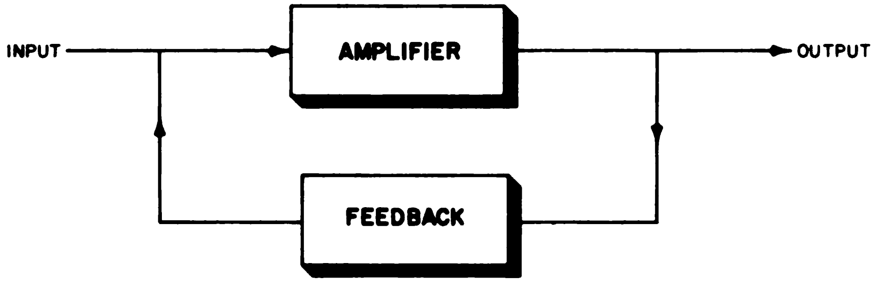
Unfortunately, the presence of a time delay in a servo system tends to cause the applied torque to be proportional to the past error rather than to the present error. The torque reverses every time the error is reversed. The greatest amount of torque is developed at the instant when the peak of the waveform, or maximum angular displacement, is reached. When the controller time delay is introduced, the corrective torque lags by some angle (ϕ) and is applied in the wrong direction after the load swings past the zero-error position. The torque arrows show that a maximum torque is no longer developed at the waveform peak but at some distance after the peak has been reached. This distance is equal to lag angle ϕ in degrees. Therefore, the time delay in the controller creates a regenerative or positive action by increasing the oscillations each time the load swings by the ordered position.

Undesirable Effects of Oscillation

The undesirable effects of oscillation or hunting in Naval servo systems are obvious. Directors must synchronize with target designation with a minimum of overtravel and with no oscillation after synchronization has been achieved. The target designation from the search radars must be a fixed signal with no oscillation transmitted to the directors. Directors must transmit to the computers a smooth signal free from oscillation or hunting, and the computers must be able to transmit bearing and elevation orders to guns and missile launchers without oscillation or hunting. Transmission of rudder angle from the wheel in the pilot house to the steering engine room must be without oscillation or hunting.

Elimination of Hunting and Oscillation

As defined previously, feedback is the method by which a sample of an output is returned or fed back to the input to be added to or subtracted from the input, thereby changing and controlling the output.

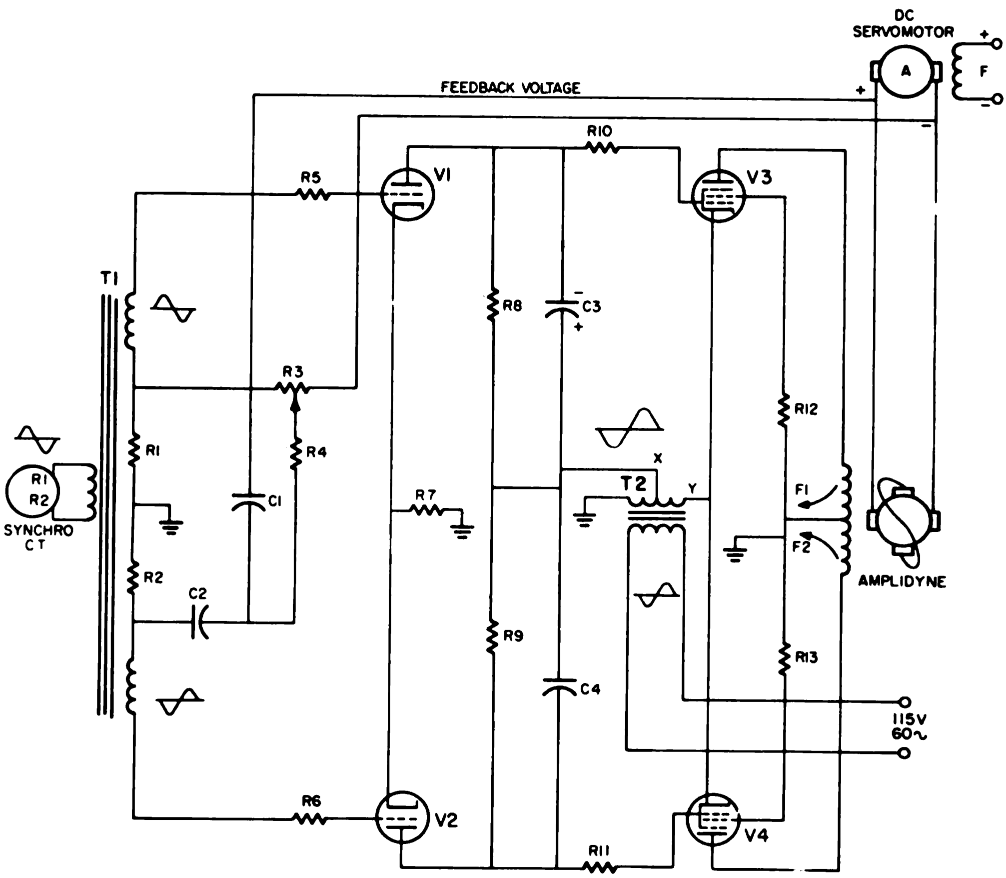


100. Amplifier Feedback

Feedback improves servo system stability by using any one or a combination of the following methods: reducing the output impedance, increasing the input impedance, reducing noise, reducing phase shift, and/or improving frequency response. An electronic antihunt circuit is the preferred method. It is capable of acting as a positive feedback to increase the gain of the servoamplifier when the error signal is increasing; it also acts as a negative feedback to reduce the gain of the amplifier when the error signal is decreasing.

Elimination of Hunting and Oscillation (Continued)

The accompanying schematic diagram illustrates a circuit for positive or negative feedback in a phase-sensitive servoamplifier. Because this circuit is capable of developing either positive or negative feedback, it may be called an antihunt circuit. The components of the illustrated example are R3, which is the gain control; resistors R1, R2, and R4; and capacitors C1 and C2.



101. Phase-Sensitive Servoamplifier

Elimination of Hunting and Oscillation (Continued)

When the servomotor rotates the load to the ordered position, the error voltage developed by the CT is zero. Therefore, the input to the servoamplifier is zero; the output of the servoamplifier is zero; and the excitation voltage to the controlled phase winding of the servomotor is zero. If the load would then rotate to the ordered position and stop, the situation would be ideal; but, because of inertia, the load has a tendency to overshoot the ordered position. The antihunt circuit is employed to develop a feedback voltage which will counteract the effects of load inertia.

The antihunt circuit controls the bias of the first stage of the servoamplifier in the following manner:

1. Changes in the DC output voltage to the servomotor are fed back and applied to the end terminals of potentiometer R3.
2. Capacitor C1 and resistor R4 make up an R-C type filter which smooths the half-wave generator ripple.
3. Any portion of the feedback voltage may be selected for proper antihunt operation by adjustment of the wiper arm of the potentiometer.
4. The voltage is applied across the series combination of R1 and R2 through capacitor C2.
5. As the generator output voltage increases in response to the error voltage signal, capacitor C2 starts to charge through resistors R1 and R2. The charging current flows through both resistors.
6. The polarity of the resulting voltage drop across R1 is negative at the ground end and positive at the above ground end.
7. This positive bias helps the positive error-voltage swing at the grid of the triode V1, thereby placing a larger positive signal on the grid of V1 than ordered by the error signal.
8. The servomotor rotates faster in the proper direction.
9. When the output voltage levels off to a constant value, C2 (having reached its maximum charge) draws no further current through R1 and R2.
10. The input to the servoamplifier is now only an error signal.
11. As the ordered position is approached, the error voltage and the generator output voltage decrease.

Elimination of Hunting and Oscillation (Continued)

12. When the feedback voltage decreases, C2 starts to discharge through R1 and R2.
13. Because the discharge of C2 is in a direction opposite to its charge direction, voltages which are the reverse of the charging voltages appear across R1 and R2.
14. The negative voltage across R1 now opposes the error-voltage signal, which causes the output voltage to fall lower than the ordered signal.
15. The load is thereby slowed as it approaches the ordered position, and hunting is avoided.

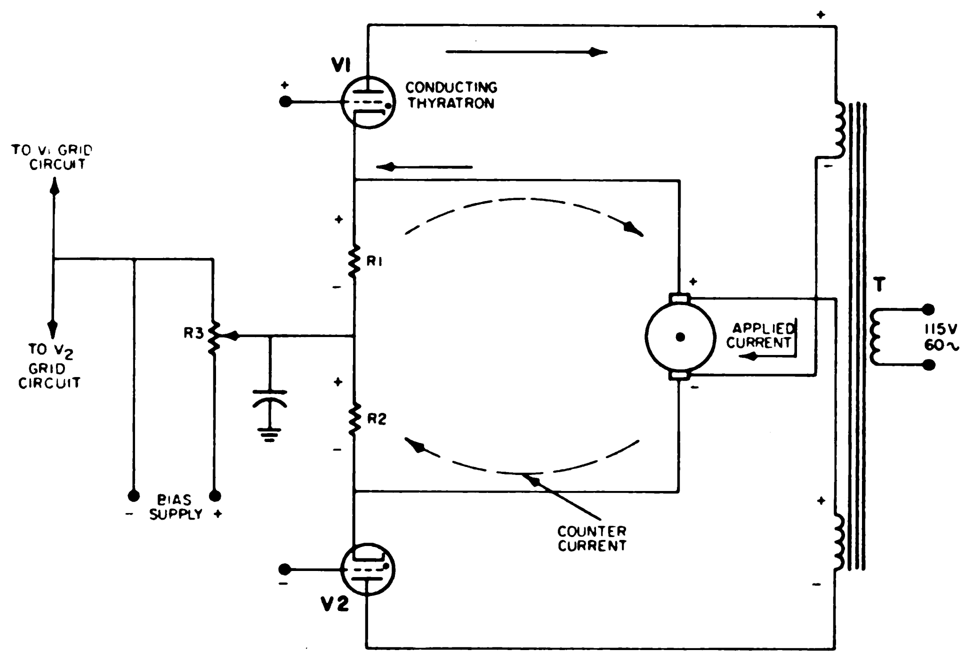
When the potentiometer is properly adjusted, the generator output will fall to zero at the right time to compensate for the inertia of the load and any other disturbing influences. At this point, hunting has been eliminated.

If the potentiometer setting is too high and the picked-off feedback voltage is too large, the load will stop its motion while the CT rotor is still out of the zero error voltage position. The servomotor will then start up rapidly, thereby setting up a condition for high frequency hunting.

Conversely, if the potentiometer setting is too low for adequate feedback voltage, the negative feedback effect will not be enough to overcome the load inertia. Some low frequency hunting will result.

The polarity of the feedback voltage with respect to the antihunt network must aid the start of the load rotation and retard the load as it comes to a stop. If the polarity is reversed so that the antihunt network hinders rotation at the start and accelerates rotation at the end, a violent hunting will occur; and serious damage to the equipment may result.

Elimination of Hunting and Oscillation (Continued)



102. Use of Counter-Electromotive Force as Antihunt Device

Another system to eliminate hunting is known as counter-electromotive force. In this circuit, with a no error condition assumed, the fixed grid bias is adjusted by means of potentiometer R3 so that V1 and V2 cannot fire. When an error voltage is present and has a phase relationship to the reference voltage (as shown by the polarity symbols), V1 conducts. Current then flows through the DC motor armature in a direction indicated by the arrows, causing armature rotation.

Elimination of Hunting and Oscillation (Continued)

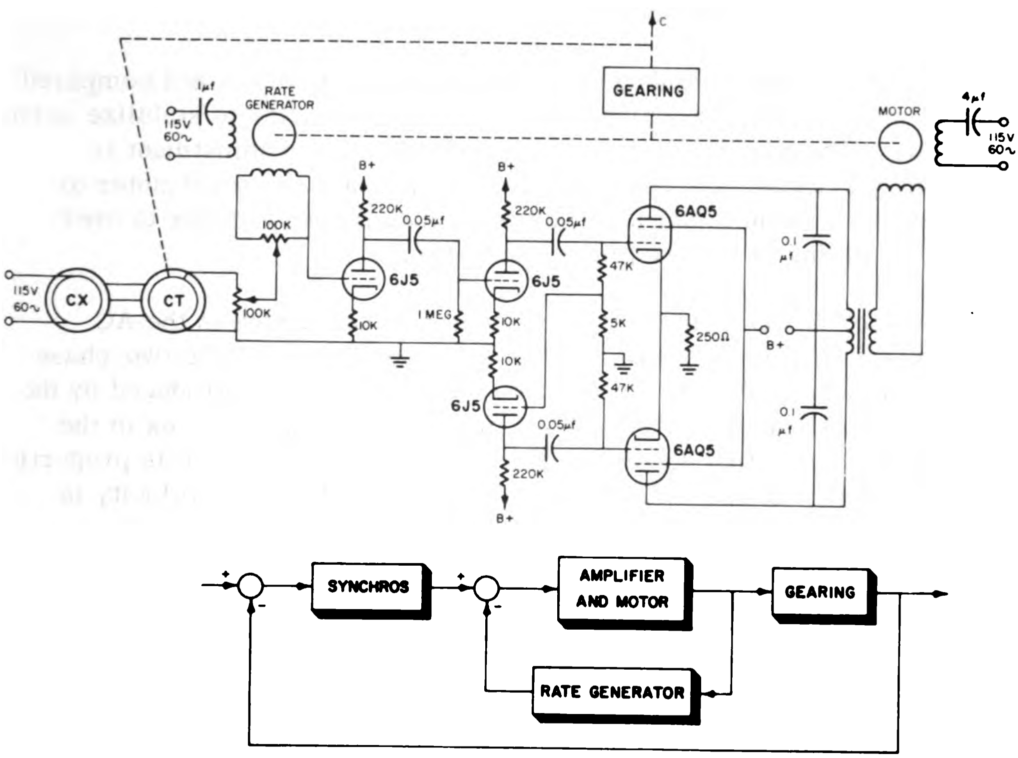
While rotating, the armature tends to act as a generator; it develops a counter-electromotive force with the polarity indicated. Thus, the current produced by the counter-electromotive force opposes the applied current. Because the series combination R1 and R2 tends to increase the negative bias on V1 and to provide a negative feedback, this action stabilizes the armature current to a constant value. As the error voltage decreases, V1, being biased by the fixed supply and the addition of the drop across R1, is cut off just before the load reaches the ordered position. At this instant, V2, which is biased by the fixed supply less the drop across R2, conducts momentarily. The reversed current to the armature then acts as a brake, which quickly checks the load motion. Therefore, with proper circuit constants and accurate adjustment, this device eliminates overshoot and hunting.

Another device used quite frequently for servomechanism stabilization is the tachometer or rate generator. The tachometer has two stator windings: an excitation winding and an output winding. The excitation and output windings are placed at right angles to each other in the stator. One winding is energized by an AC supply voltage. Due to the geometry of the coils, no output voltage is induced when the rotor is stationary.

As the rotor rotates, the flux produced by the eddy currents changes direction and produces a component of flux in the direction of the output winding. A voltage at the reference frequency is developed across the terminals of the output winding, the amplitude of this voltage being proportional to the angular velocity of the shaft.

Elimination of Hunting and Oscillation (Continued)

The direction of the shaft velocity is indicated by the phase of the output voltage. If the output is in phase with the reference voltage, the velocity direction is considered to be positive. If the output is 180° out-of-phase with the reference voltage, the velocity direction is considered to be negative. A typical servo application of a rate generator used in an instrument servo is shown in the accompanying circuit and block diagram.



103. Example of a Servomechanism with a Rate Generator

ANTIHUNT IN SERVO SYSTEMS

Summary

Oscillations can be eliminated by means of mechanical, frictional devices such as dampers or by the use of electronic devices. Electronic devices usually employ some method of feedback and are preferred because they do not absorb power as frictional devices do.

Time delay, the delay present in the controller between the time an error appears and the time a torque is applied to correct the error, causes hunting and oscillation in servos. The effect of time delay causes the torque applied to the output shaft to be proportional to the past error, thereby causing continuous hunting.

Feedback, the means by which output data is fed back and compared to the input, is used in conjunction with a potentiometer to stabilize servo systems. The potentiometer is the gain control; this adjustment is extremely critical. Excessive feedback will cause the servomotor to stop too soon; insufficient feedback will cause the servomotor to overshoot, resulting in low frequency oscillation.

Another device commonly used as an antihunt device is the AC tachometer or rate generator. This device is similar to the two-phase induction motor. As the flux is made to rotate, the flux produced by the eddy currents changes direction and produces a component flux in the direction of the output winding. The amplitude of the voltage is proportional to the shaft angular velocity. The direction of the shaft velocity is indicated by the phase of the output voltage. If the output is in phase with the reference voltage, the velocity direction is positive; if the output is 180° out-of-phase, the direction is negative. The AC tachometer produces a viscous damping which stabilizes the servo system.

STUDENT NOTES

TOPIC 6. DC SERVO SYSTEM

You Are Now Going to Learn:

1. Advantages of the DC servo system.
2. Comparison of AC and DC servo systems.
3. Function of DC servo system components.
4. Example of a servo system.
5. Naval applications of the DC servo system.

Discussion Points for This Topic Are:

1. DC servo system.
2. DC motor theory.
3. AC and DC servo system differences.
4. Error detectors, amplifiers, motors, and stabilizing networks.

ASSIGNMENT:

PURPOSE:

To become familiar with the advantages and functions of a DC servo system.

TOPIC 6. DC SERVO SYSTEM

Advantages of the DC Servo System

The DC servo system has certain inherent advantages over the AC system, especially when large amounts of power from thyratrons or motor-generator amplifiers are required for operation and when variable speed and speed torque characteristics at high efficiency are necessary.

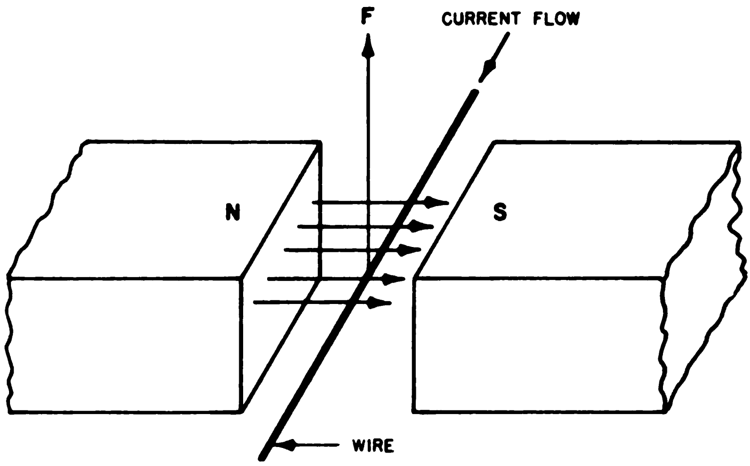
Closed-loop servo systems employ a variety of DC motors. Series, shunt, compound, or externally excited types are widely used for the control of speed and torque. DC motors range in size from a few watts, driven by vacuum tube amplifiers, to several hundred horsepower, driven by Ward-Leonard generators or rotating amplifiers.

Review of DC Motor Theory

The basic physical components of a DC motor are field windings, armature windings, and a commutator. Torque is the rotary motion developed when current-carrying conductors arranged around the surface of an armature cut through the lines of force generated by the magnetic field of a stator. Thus, torque is developed due to the magnetic forces reacting between the field poles and the armature windings.

Field Winding. The field winding consists of a number of coils. Each coil is wound around a field pole. When current is passed through the coil, the field pole becomes magnetized.

Review of DC Motor Theory (Continued)



104. Force on Single Conductor in Magnetic Field

As illustrated in the diagram, the force exerted on a single conductor is proportional to the product of the field strength in the vicinity of the conductor, the current through the conductor, and the length of the active part of the conductor. Also, the force is exerted in a direction perpendicular to both the magnetic lines of force of the field and the current-carrying conductor.

Armature Winding. The armature winding consists of coils distributed around the periphery of the armature. The ends of each coil are connected to form a closed winding and then connected to separate bars or contact points of the commutator.

Commutator. During rotation, the commutator acts as a multi-position switch whose poles are the brushes connected to the external circuit. Rotation causes a switching action which continuously connects the armature coils so that the armature conductors lying under the north pole carry currents flowing in one direction, while those lying under the south pole carry currents in the opposite direction. The commutator reverses the current in each armature coil at the instant it passes through the neutral axis or when it leaves the influence of the north pole field and enters the influence of the south pole field. This action affects each armature conductor.

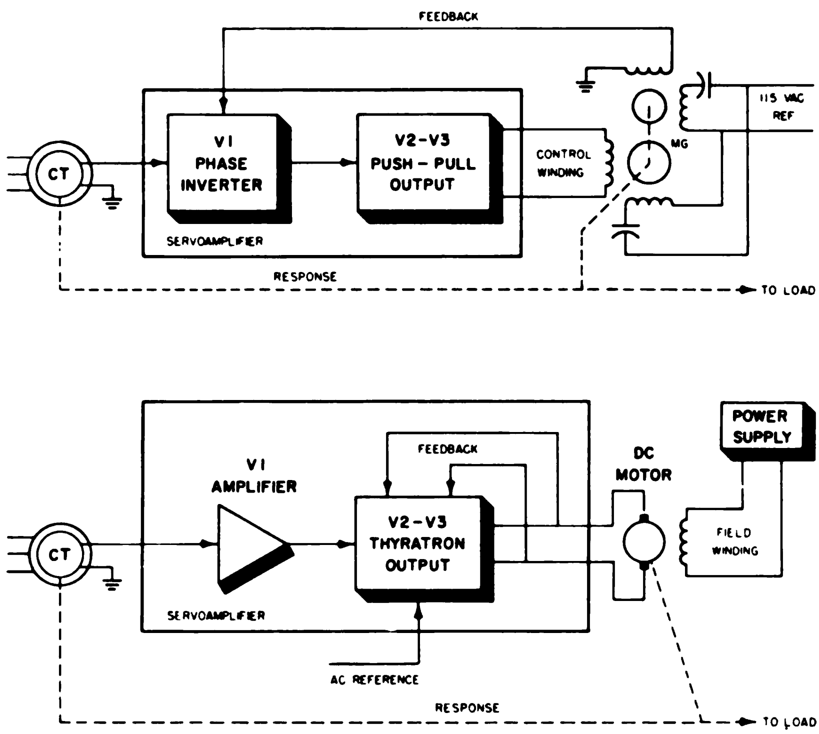
DC SERVO SYSTEM

Comparison of DC and AC Servo Systems

The components of AC and DC servomechanisms are determined by the requirements of the end function. Servomechanisms which need high-power and wide-speed range applications use DC amplifiers and motors; servomechanisms which require low speed and low power use AC systems.

Servo systems, whether DC or AC, have the same basic components: error detector, amplifier, motor, and load. Error detecting devices, such as synchro control transformers and potentiometers, are common to both DC and AC servos. Amplifier and motor requirements differ in the two systems. The DC amplifier must convert an AC input into a DC output; it must vary the output as the input varies; and it must be able to reverse the polarity of the DC output as the phase of the AC input reverses. The AC servoamplifier amplifies the error signal and applies it to one winding of the two-phase induction servomotor. The AC servomotor, for all intents and purposes, is a constant speed device, while the DC motor of a DC servo system may be driven at variable speeds.

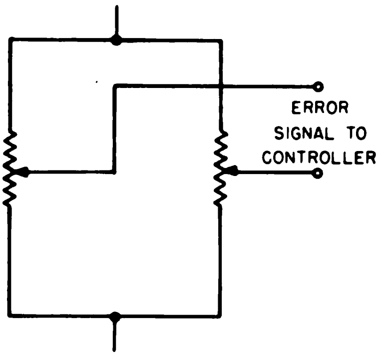
Comparison of DC and AC Servo Systems (Continued)

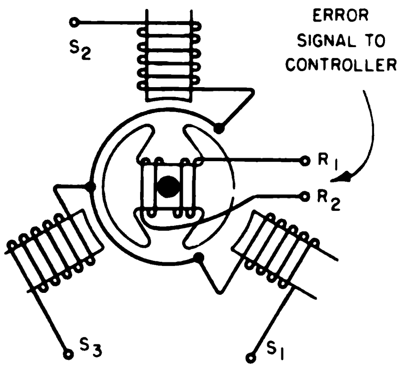


105. Block Diagrams of AC and DC Servo Systems

Function of DC Servo System Components

A DC servo has the same basic components as an AC servo: error detector, amplifier, and motor. Like the AC servo, the DC servo incorporates the stabilizing effects of feedback and response.



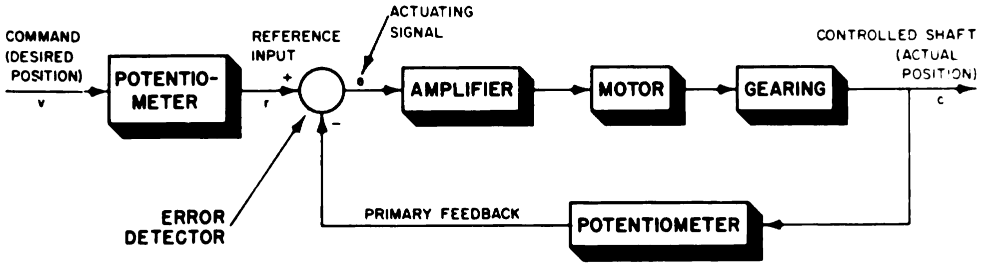


106. Error Detector Devices: Balanced Potentiometers and Control Transformer

Error Detector. The error detector is the device that senses the difference between the command input and the present load and then produces an error voltage of the correct polarity or phase to cause the servo systems to drive in the proper direction to the command position.

Potentiometer systems operate on the balanced bridge principle. The input potentiometer makes up two legs of the bridge and the potentiometer geared to the servomotor output provides the other two legs. The servo comes to rest when the bridge is in balance at zero output.

Control transformer systems balance out the error voltage by connecting mechanical response to the control transformer rotor.



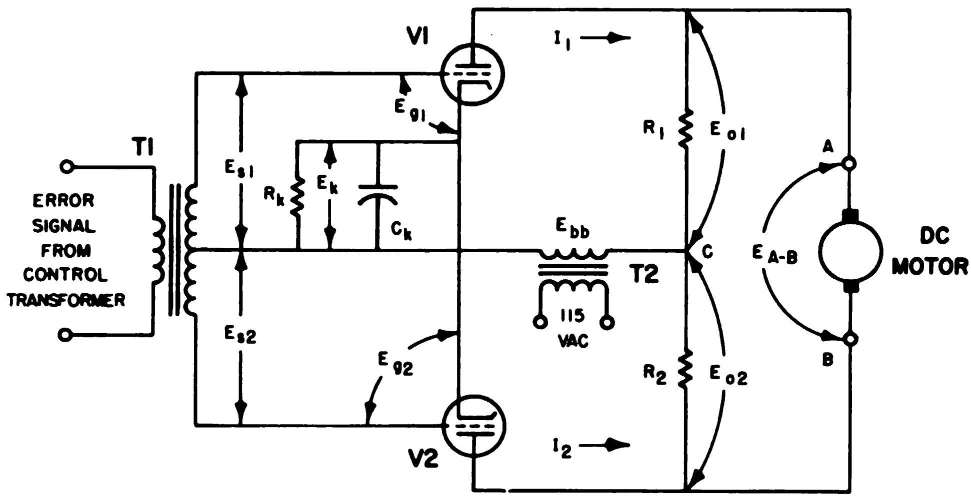
107. Error Detector in Servo System

Function of DC Servo System Components (Continued)

Amplifier. A DC servoamplifier meets the same basic requirements as an AC amplifier. In addition, it must convert an AC error signal input into a DC power output; and it must be phase-sensitive. A single stage, two-tube DC amplifier; can achieve these requirements.

The circuit in the diagram looks somewhat similar to a conventional push-pull output stage. Close examination, however, shows the dissimilarity: the B+ supply, which normally supplies the plates with DC voltage, has been replaced by an AC voltage source. The permanent magnet motor is connected to each plate as a load. A transformer and a coupled push-pull circuit make up the grid circuit. The control transformer provides the input error signal that is applied to the two grids which are 180° out-of-phase. The error signal is an AC voltage that must be converted to a DC voltage, and the polarity must reverse as the phase of the error signal reverses. When there is no error signal, the servo system is at rest; thus, the output of the servomotor is zero.

Function of DC Servo System Components (Continued)



108. Single Stage DC Amplifier

E_{s1} and E_{s2} — The error signal voltages.

E_{g1} and E_{g2} — The grid-to-cathode voltages.

E_k — The bias voltage on both tubes.

I_1 and I_2 — The instantaneous plate currents.

E_{bb} — The instantaneous plate voltage.

E_{o1} and E_{o2} — The instantaneous voltage drops across resistors R1 and R2, with reference to their common connection point C.

E_{A-B} — The instantaneous voltage, taken from A to B, across the DC motor.

R1 and R2 — The plate load resistors, which are equal in value.

T1 — The input transformer.

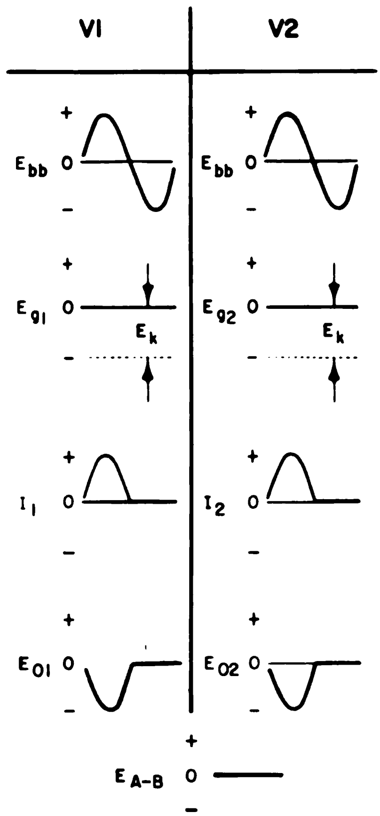
T2 — The plate transformer.

V1 and V2 — The amplifier tubes.

R_k — The cathode-biasing resistor.

C_k — The cathode-bypass condenser.

Function of DC Servo System Components (Continued)



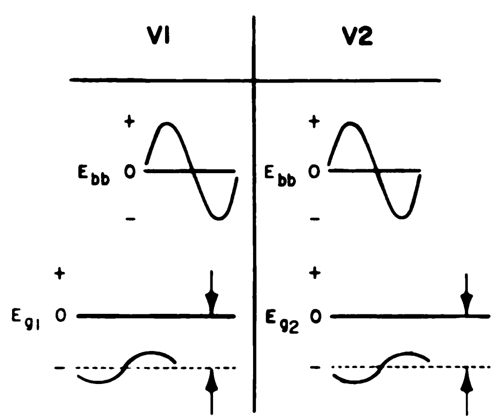
109. Relationships Between Plate Voltage, Plate Current, and Grid Bias When the Servomotor Is At Rest

Illustrated waveform E_{bb} is the AC voltage which is applied to the plates of both triodes. Voltages of both plates are in phase because both plates are connected to the same point on transformer T2. Waveform E_g is the grid-to-cathode voltage. Because input signal E_s is zero, the grid-to-cathode voltage is the bias voltage developed across cathode-bias resistor R_k. Since the cathodes are connected together, the bias is the same for both tubes. Plate current waveforms I_1 and I_2 have the same shape as the plate voltage waveform for the first half cycle. During the second half cycle, the plate voltage is negative; therefore, the plate current is zero.

Function of DC Servo System Components (Continued)

Since I_1 and I_2 are equal and since R1 and R2 are equal, voltage drop E_{o1} and E_{o2} must also be equal. With the DC motor connected across R1 and R2, the voltage across the motor is equal to the sum of the voltage drops across R1 and R2. Voltage drops E_{o1} and E_{o2} are in series but are also in opposition from point A to point B; therefore, the voltage (E_{A-B}) across the motor is the difference between E_{o1} and E_{o2}. In the illustrated situation, E_{A-B} is zero; therefore, the motor will not rotate.

For the next condition, there is an error signal output from the control transformer. The grids are connected in push-pull and are 180° out-of-phase. Thus, when a signal is applied to the primary of input transformer T1, one grid will be positive and the other grid will be negative with respect to the center tap on the secondary winding. Thus, grid-to-cathode voltage E_g is no longer equal to the bias voltage. Now grid signal E_s determines the amount of grid-to-cathode voltage variance above or below the bias voltage. The waveforms show the grid signal either in-phase or out-of-phase with the plate voltage. Because the synchro system and the servoamplifier are energized from the same AC line, the error signal is either in-phase or out-of-phase with the line-voltage, if there is no phase shift in the synchro system.

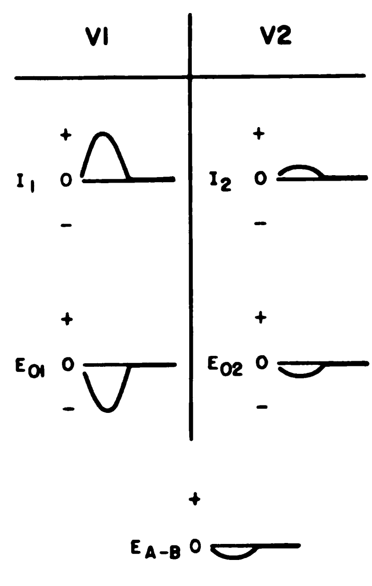


110. Waveform Relationships When Grid-To-Cathode Voltage Does Not Equal Bias Voltage

Function of DC Servo System Components (Continued)

If, during the first half cycle, error signal E_{s1} is in phase with plate voltage, the grid voltage of V1 will decrease, causing plate current I_1 to increase. Conversely, if error signal E_{s2} is 180° out-of-phase with plate voltage, the grid voltage of V1 will increase, causing plate current I_2 to decrease. During the second half cycle, the plate voltage of both V1 and V2 is negative with respect to the cathodes; therefore, current does not flow in either tube.

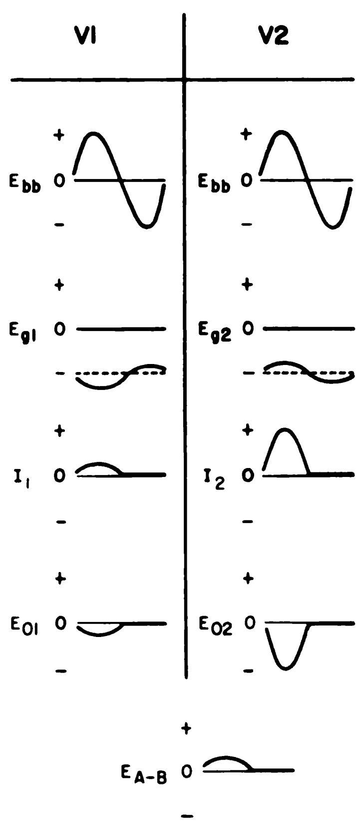
An increase in plate current I_1 increases the voltage drop E_{o1} across R1. A decrease in plate current I_2 decreases the voltage drop E_{o2} across R2. The difference between E_{o1} and E_{o2} is E_{A-B}, which is the voltage impressed across the motor. Voltage E_{A-B} causes current to flow through the armature of the motor, producing counterclockwise rotation.



111. Waveform Relationships When Voltage Across the Motor Causes Counterclockwise Rotation

Function of DC Servo System Components (Continued)

Reversal of the error signal output from the CT causes reversal of the phase of the signal voltages on the grids. The grid of V1 is then negative with respect to the center tap; the grid of V2 is positive with respect to the center tap. Voltage E_{s2} is in phase with the plate voltage, while E_{s1} is out-of-phase with the plate voltage. Plate current at the plate of V1 decreases, and the plate current of V2 increases. A decrease in current I_1 causes a decrease in output voltage E_{o1}; an increase in current I_2 causes an increase in output voltage E_{o2}. Therefore, the output voltages are not equal. This condition causes a voltage E_{A-B} across the motor; this voltage is the difference between voltage E_{o1} and E_{o2}. The polarity of the output voltage E_{A-B} becomes that of E_{o2}, which is the larger output. Because the polarity of the motor has reversed, the armature current reverses. Thus, the motor turns in a clockwise direction.



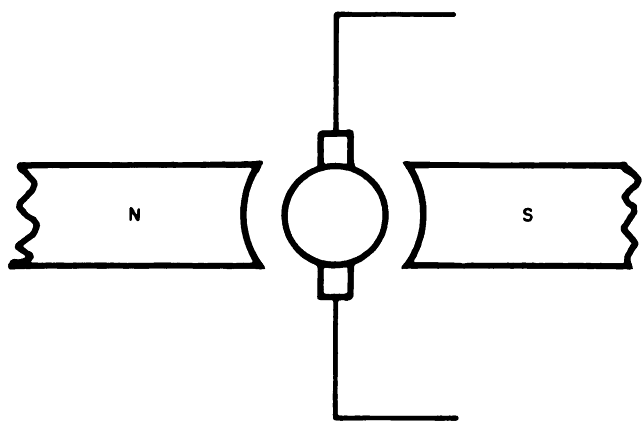
112. Waveform Relationships When Voltage Across the Motor Causes Clockwise Rotation

Function of DC Servo System Components (Continued)

Motor. Although all sizes of DC motors are used, motors over 100 watts are more efficient in the larger ratings than two-phase AC control motors. With certain exceptions, most large DC motors are used because of their superior control characteristics. They can drive loads in either direction and at variable speeds.

In this course, the emphasis will be placed on two types of DC motors: the permanent magnet field type and the shunt field type.

The permanent magnet field motor is most useful when low power DC servos are required. In this motor, the armature current is controlled directly by the servoamplifier. Since the field flux is constant, varying the armature current will reverse the direction of rotation.



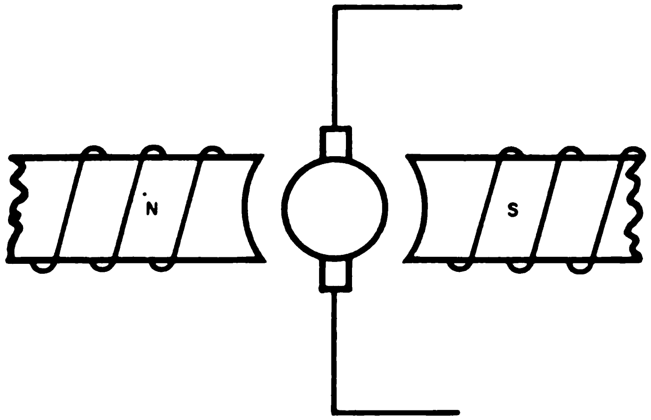
113. Permanent Magnet Field Motor

Function of DC Servo System Components (Continued)

When power requirements increase, the permanent magnet field motor becomes impractical because it is larger than a shunt motor of equal power rating. Larger power requirements call for the shunt motor, in which the field winding can be separately excited to supply a constant field flux. In addition, the armature voltage can be controlled to vary its speed and direction of rotation. These two types have the following characteristics in common:

By varying the armature voltage, the speed may be varied.

By reversing the polarity of the armature voltage, the direction of rotation may be reversed.



114. Shunt Field Motor

Function of DC Servo System Components (Continued)

Stabilizing Network. The methods used for stabilizing DC servos are basically the same as those used for stabilizing AC servos. With DC servoamplifiers, oscillation due to excessive phase shift is not encountered at low frequencies. When tube and circuit capacitances must be considered for optimum servo operation, care must be taken to prevent positive feedback at frequencies higher than the actual operating frequencies. The amplifier utilizes the output voltage; this is the feedback voltage fed back to the amplifier input. Positive feedback adds to the input and causes the amplifier output to increase. Negative feedback is 180° out-of-phase with the applied signal and decreases the gain.

The gain of the feedback amplifier may be expressed as:

$$\text{gain} = \frac{A}{2-BA}$$

where A is the gain of the amplifier without feedback and B is the ratio of the feedback voltage to output voltage.

If the quantity 1-BA is less than 1, the gain is increased and is positive. If the quantity BA is increased until it equals 1, the amplifier starts to oscillate. If the quantity 1-BA is greater than 1, the feedback becomes negative and the amplifier gain is reduced. If the feedback is large, which occurs when BA is much larger than 1, the gain is small:

$$\text{gain} = \frac{1}{-B}$$

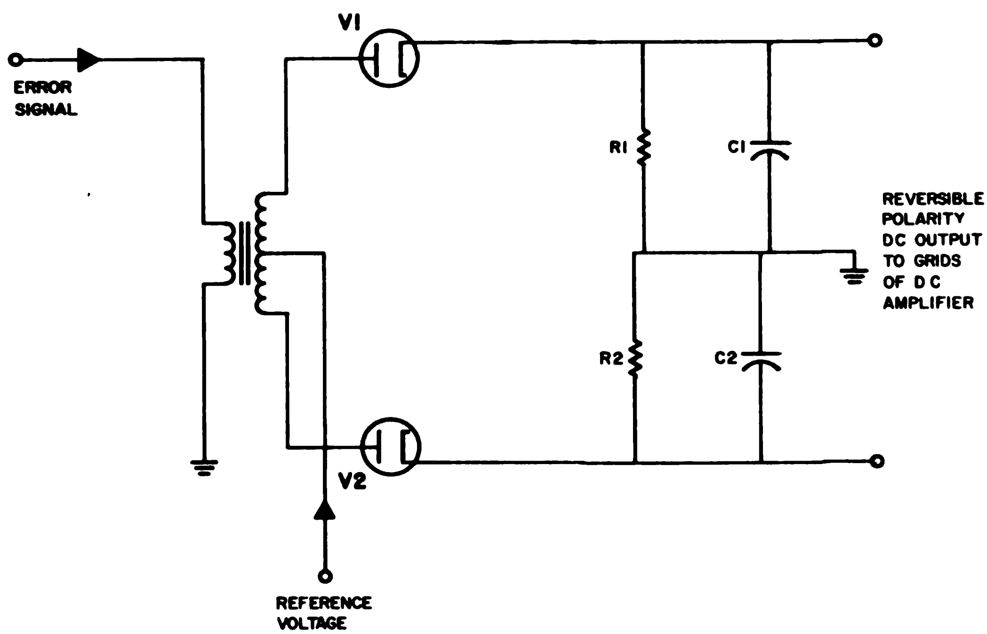
The minus sign designates a phase relation of 180° between input and output. Thus, the effect of feedback is to reduce the gain of the amplifier and to provide stability.

Feedback alone is not enough to stabilize DC servo systems. DC amplifiers have problems with drift. Drift is the low frequency variation of the output voltage with no change of input. It requires special bias voltages in cascaded stages. Drift is usually caused by changes in power supply voltages or by the change of component value due to temperature variations, aging effects, and humidity. These disadvantages

Function of DC Servo System Components (Continued)

can be overcome by incorporating DC equalizing networks, modulation and demodulation networks, or by using choppers to modulate the input voltage and choppers to rectify the output.

Phase detectors or demodulators are used frequently in DC servos to convert alternating voltage to direct voltage. Actually, it is the variation in amplitude from positive to negative rather than the phase angle that is important. The circuit shown here uses diodes instead of the phase-sensitive triodes of the previously described amplifier.



115. Phase-Sensitive Rectifier Using Diodes

Function of DC Servo System Components (Continued)

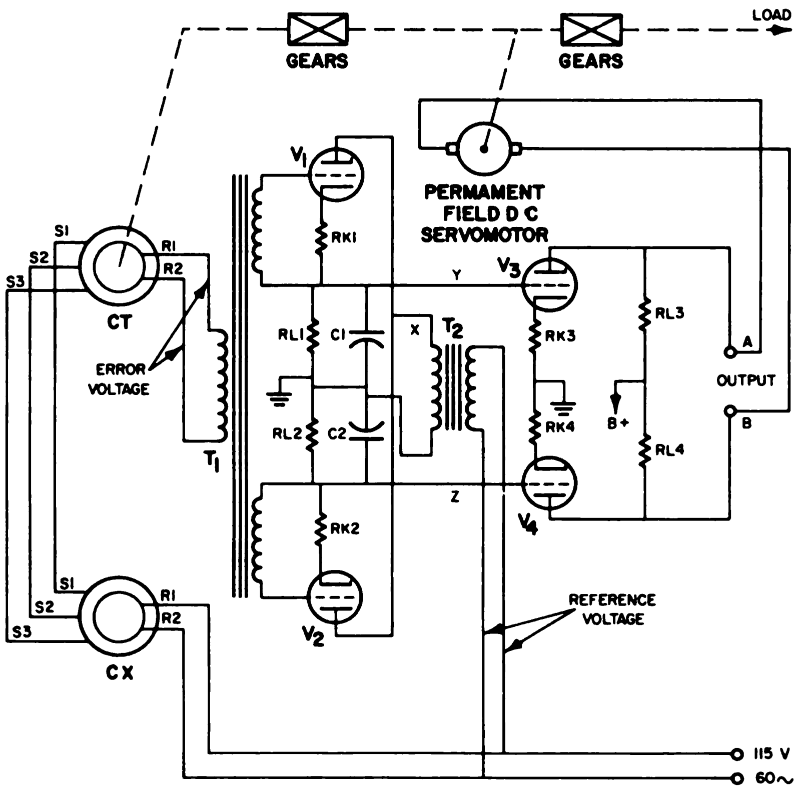
When there is no signal input, both diodes will conduct equally during the positive half of the reference plate signal. The voltages across the diode load resistors will be equal and opposite in polarity; therefore, no output will exist across the two capacitors. An error signal input makes one diode plate more positive than the other during the conducting portion of the cycle. The polarity of the error signal determines which diode plate is more positive. Conduction occurs in the more positive diode, and more current flows in this diode. Thus, the voltage drop in the load resistors is no longer equal, and a DC voltage difference is applied to the grids of the DC amplifiers. The polarity of this DC output depends upon which diode is conducting the larger amount; this, in turn, depends upon the phase of the error signal. The two capacitors act as filters to eliminate the ripple from the DC pulsating output.

Example of a DC Servo System

The DC servo system in the illustration is a simple positioning servo in which the amplifier supplies the power to the motor armature to cause rotation. The servoamplifier consists of a phase-sensitive detector amplifier, V1 and V2, coupled to a DC amplifier, V3 and V4, by a cathode-loading arrangement. The error voltage from the synchro control transformer is coupled into the amplifier through transformer T1. The plate supply for V1 and V2 is an AC voltage taken from the secondary of transformer T2. The windings of T2 are connected so that the plate voltages of V1 and V2 are in phase; both voltages swing positive or negative at the same time.

In order that the grid and plate returns may be grounded, load resistors R_{L1} and R_{L2} are placed in the cathode circuits rather than in the plate circuits. The grids of V3 and V4 are fed from the high sides of R_{L1} and R_{L2}; each resistor is supplied with a DC voltage filtered by shunt capacitors C1 and C2. The balance of the DC amplifier circuit is conventional, with a B+ supply from a rectified power supply applied at the junction of load resistors R_{L3} and R_{L4}.

Example of a DC Servo System (Continued)



116. Servomechanism Showing Amplifier Control of DC Servomotor

Example of a DC Servo System (Continued)

With no error voltage applied, both V1 and V2 conduct equally when point X is positive. As a result, both output Y and output Z will be of the same positive DC potentials. These outputs cause V3 and V4 to conduct the same amount and provide equal voltage drops across R_{L3} and R_{L4}. Thus, the output to the servomotor is zero. When point X swings negative, neither V1 nor V2 conducts. The grids of V3 and V4 are balanced by the equal potentials from C1 and C2, and the output voltage to the servomotor armature remains at zero. When an error voltage is present so that the grid of V1 is positive at the same time as point X, plate current through V1 increases while that through V2 decreases. Since point Y is now more positive than point Z, V3 conducts more heavily than V4, thereby effecting an unbalance in the voltage drops across R_{L3} and R_{L4}. This results in a negative output to the servomotor at point A with respect to point B. When the error signal is reversed 180° in-phase, V2 and V4 become the heavier conducting vacuum tubes. They cause the polarity at point A with respect to point B to reverse from the previous condition.

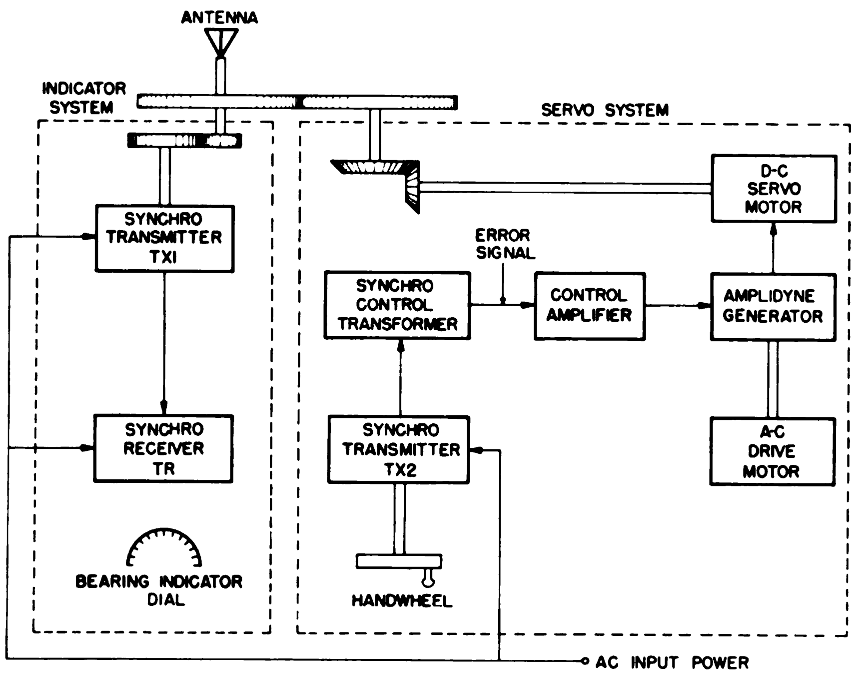
It can be seen then that the phase relationship between the error and reference voltages determines the direction of the servomotor rotation. The speed of motor rotation depends upon the magnitude of the error voltage. The schematic diagram shows that the output shaft is geared to the CT rotor in the usual manner and turns in the proper direction to reduce the error voltage to zero. The position of the load is reported to the command position by the synchro indicator system, shown on the left side of the diagram.

Naval Applications of the DC Servo System

A typical servo system using a DC servomotor is illustrated in the accompanying block diagram. Because of the instability and drift of DC servoamplifiers, this system uses an AC amplifier which converts the input to a usable DC output signal. In this application, the DC motor is used because of its large power output characteristic.

Naval Applications of the DC Servo System (Continued)

A large power output is required to rotate a search radar antenna and to hold it steady against wind, roll, pitch, and acceleration forces caused by the motion of the ship. When it is in the search mode, the rotor of the CT is driven by a small, constant speed, AC motor. The speed, however, may be varied by the radar operator. When the radar is in the track mode, the antenna is positioned manually by means of a handcrank.



117. Typical Servo System Showing DC Servomotor

This servo loop is somewhat different from the conventional loop in that the CT rotor is positioned either directly by means of a motor or manually by the radar operator. It is not positioned by the response. In this case, the response is electrical because the action of the antenna drive motor positions the rotor of the CX and induces a voltage into the stator of the CX. The response voltage is fed to the stator of the CT in order to cancel the signal voltage from the rotor of the CT.

DC SERVO SYSTEM

Naval Applications of the DC Servo System (Continued)

Depending upon the position of the true-relative switch, the electrical response from the stator of the CX may take one of two paths. When the switch is set at RELATIVE position, the electrical response is fed directly from the CX to the CT. This position of the switch causes the dial on the rotor of the CT to indicate relative bearing of the radar antenna. If the switch is set at the TRUE position, the response is diverted through the CDX. The mechanical input to the rotor of the CDX and the value of own ships course are added to the response so that the bearing indication of the radar antenna becomes the true bearing. If the rotor of the CT is held constant by handcrank friction, the servomotor will drive the antenna to the fixed true-bearing position because the ships course input is fed to the stator of the CDX.

Summary

Fundamentally, DC servos are similar to AC servos. They both meet the basic requirements for a servomechanism and have essentially the same components. The DC servo, however, must convert an AC input into a DC output. It must be able to vary the DC output as the input varies and to reverse the polarity of the DC output as the phase of AC input reverses. Unlike the AC servomotor, the DC servomotor may be driven at variable speeds.

A disadvantage of DC servos is their tendency to drift. Drift is caused by aging of amplifier tubes and by changes in the component characteristics that are sensitive to temperature and humidity changes. To overcome these difficulties, equalization circuits are incorporated into the servoamplifier.

In Naval equipment, DC servos are used primarily when heavy loads must be positioned. For example, they are found in gun turrets, missile launchers, sonar transducers, and radar antennas.

STUDENT NOTES

TOPIC 7. SERVOAMPLIFIERS USING THYRATRONS

You Are Now Going to Learn:

1. Characteristics of the triode gas tube.
2. Operation of a thyratron servoamplifier with an error signal input.
3. Applications of the thyratron servoamplifier to Naval equipments.

Discussion Points for This Topic Are:

1. Low plate resistance.
2. Grid control.
3. Critical grid voltage.
4. Phase-shift control.
5. Navy use of thyratron servoamplifiers.

ASSIGNMENT:

PURPOSE:

To become familiar with thyratrons, the operation of thyratron, the advantages of thyratrons, and the applications of thyratrons.

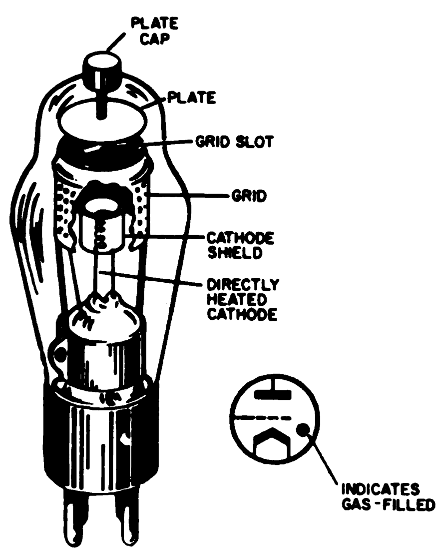
TOPIC 7. SERVOAMPLIFIERS USING THYRATRONS

Characteristics of the Triode Gas Tube

A thyratron is a three-element gas tube. It consists of a glass envelope containing an inert gas, a directly heated cathode, a plate, and a control grid between the cathode and the plate.

Vacuum tubes are used for power amplification when the output power required is 25 watts or less. Thyratrons are often used for those applications requiring power outputs up to ten horsepower.

One type of thyratron tube used quite frequently in servoamplifiers is the 3C23. This tube has a directly heated cathode made of heavily thoriated tungsten for high emission. The filament is rated at 2.5 volts at 7 amperes for a total filament power of 17.5 watts; this insures a large cathode emission. The illustrated schematic symbol for the 3C23 thyratron is the same as that for the directly heated, triode vacuum tube; the dot indicates that the tube is gas-filled.



118. 3C23 Thyratron Tube

Characteristics of the Triode Gas Tube (Continued)

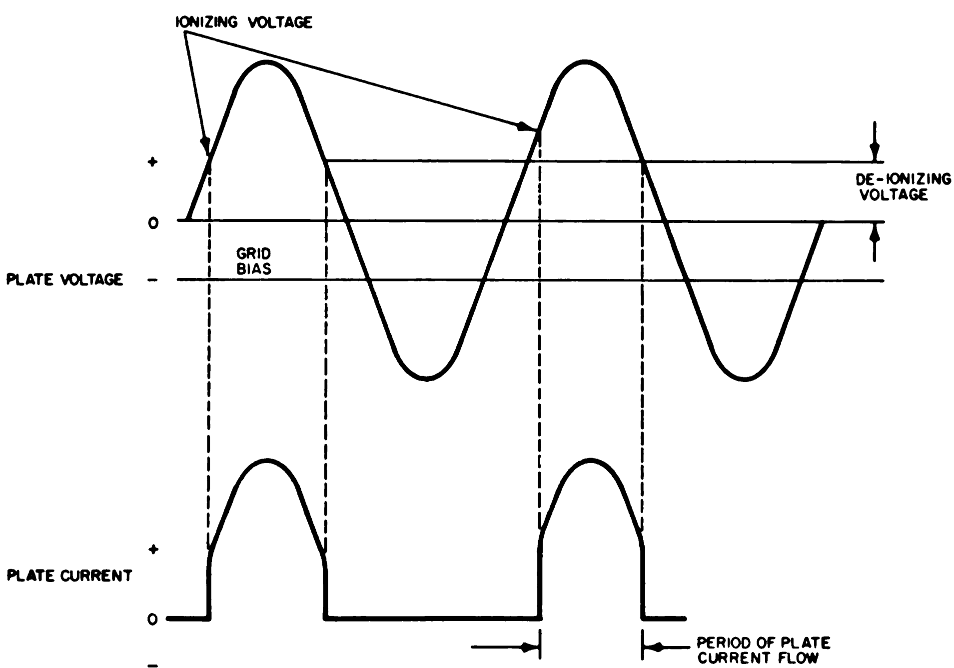
Low Plate Resistance. One advantageous characteristic of a thyratron is its low anode or plate resistance which enables the tube to conduct large amounts of current. When the thyratron conducts, gas atoms are ionized by collision with electrons emitted from the cathode. The positive ions of gas are attracted to the negative space charge which surrounds the cathode. Upon entering this negative space charge, the positive ions capture electrons and become neutral. Because the space charge region loses a large number of electrons to the gas ions, the space charge decreases in size. A smaller space charge results in a smaller force of repulsion on the electrons emitted from the cathode. Thus, a great many more electrons will be allowed to flow to the plate for a given plate voltage than would flow if there was no gas present. A larger plate current for a given plate voltage means that the internal plate resistance of the thyratron has dropped.

Grid Control. The function of grid voltage is to permit or to prevent the flow of current. Once the flow has started, however, the grid loses control because a sheath of positive ions forms on the grid structure, neutralizing the negative potential of the grid. Varying the grid potential only serves to make the sheath thicker or thinner. When plate voltage is high and the grid loses control, the thyratron conducts for any value of negative grid voltage. The grid may then be considered as not being in the circuit; therefore, the thyratron performs as a diode, the plate maintaining complete control of current flow. Conduction can be stopped only by lowering the plate voltage below the ionization level.

Because the control characteristics are not clearly defined and because the grid can be used only to start conduction, circuits for thyratron amplifiers are quite different from circuits for vacuum-tube amplifiers. In servos, an AC voltage is commonly used as the plate supply to the thyratrons; this resolves the problem of cutoff. The use of an AC voltage in this case also provides an interesting range of critical grid voltage to appear within the extremes of the sinusoidal plate voltage.

Characteristics of the Triode Gas Tube (Continued)

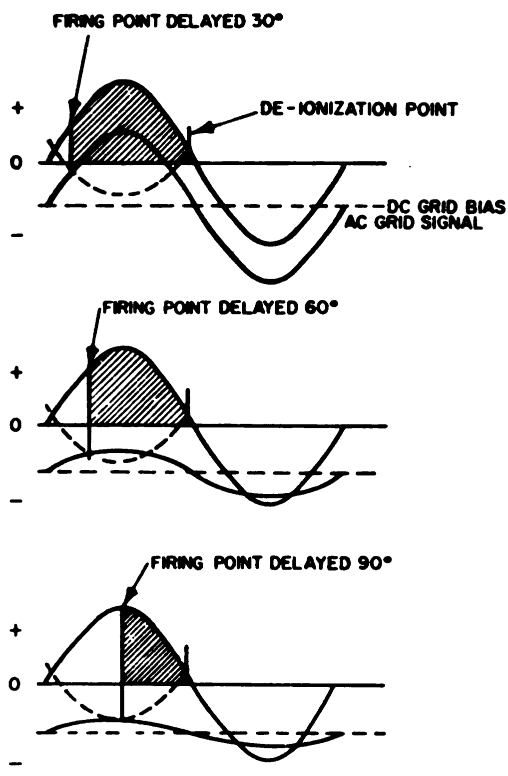
While the tube is conducting, plate current may be varied by varying plate voltage; plate current is directly proportional to plate voltage. The diagram below shows a sinusoidal voltage applied to the plate of a thyratron; directly below this is the waveform of the resultant plate current. The diagram shows that plate current does not start to flow until ionization has been reached. When the positive plate voltage is large enough to overcome the negative field of the grid, the tube fires. After the plate voltage starts dropping, a point is reached at which ionization can no longer be maintained. The tube then ceases to conduct. The point at which the tube cuts off is the de-ionization point. From this point, the plate voltage becomes more negative; the tube cannot conduct. Hence, while plate voltage is AC, plate current is pulsating DC.



119. Sinusoidal Voltage Applied to Thyratron Plate

Characteristics of the Triode Gas Tube (Continued)

<u>Critical Grid Voltage</u>. Critical grid voltage is defined as the maximum potential between the grid and the cathode that will prevent the tube from firing while the plate is positive. For each value of positive plate voltage, there is one value of critical grid voltage. It follows that, when the value of positive plate voltage is varied, the value of critical grid voltage will also vary. For an AC plate voltage varying sinusoidally from zero to peak-voltage values, the critical grid voltage varies in inverse proportion.



120. Delay of Thyratron Firing by Varying Grid Voltage

Chracteristics of the Triode Gas Tube (Continued)

In the illustrated situation, ionization can be varied by 0° to 90° by varying the critical grid voltage during the first 90° of positive plate voltage. When an AC signal, in phase with and of the same frequency as the plate supply voltage, is superimposed on the DC grid bias, the thyratron may be made to conduct during different portions of the positive half cycle of plate voltage. The illustration shows that the firing point may be delayed by varying the amplitude of the AC grid signal. Examination of the curves shows how the amplitude control method cannot delay the firing point beyond 90°. Within the 90° limit, varying the grid voltage allows the thyratron to control the speed of the servomotor.

The point at which thyratron firing takes place can be controlled by determining the grid voltage. Increasing the grid bias will cause the tube to fire later in the cycle of plate voltage. If it is necessary for the tube to fire earlier in the cycle of plate voltage, the grid bias voltage can be decreased. The firing point of the thyratron, therefore, is a combination of grid and plate voltage.

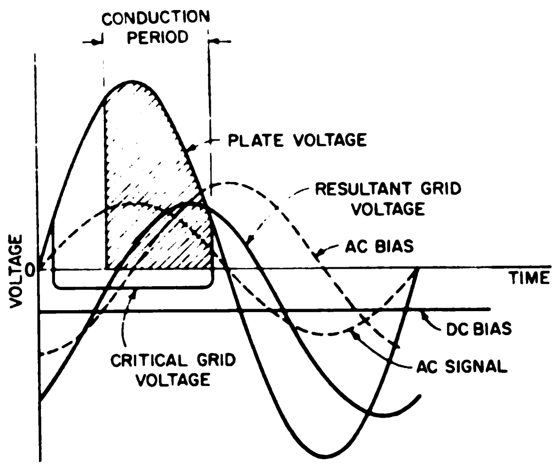
Characteristics of the Triode Gas Tube (Continued)

Phase-Shift Control. It has been shown that the firing point of a thyratron can be controlled during the first half of the positive half-cycle of plate voltage. If the firing point could be controlled beyond the 90° point, a more sensitive control would be possible. The method of phase-shift control meets this requirement.

Phase-shift control is accomplished by adding a third voltage, an AC bias, to the grid voltages discussed earlier. This AC bias is of the same frequency as the AC error signal; however, its phase can be varied in relation to the AC error signal. The three grid voltages continuously resolve themselves into one resultant voltage that has the same frequency as the AC bias and error signal and an amplitude equal to the algebraic sum of the values of the AC bias, the DC bias, and the AC error signal.

The critical grid voltage curve can be intercepted at any desired point by varying the phase of the AC bias. In other words, the firing point of the thyratron can be controlled over the entire 180° range of positive plate voltage. This provides control of current flow from zero to a maximum.

Characteristics of the Triode Gas Tube (Continued)



121. Waveform Relationships for Phase-Shift Control of Thyratrons

Characteristics of the Triode Gas Tube (Continued)

The following schematic diagram with illustrated waveforms is an example of phase-shift control. The primaries of reference transformer T1 and plate supply transformer T5 are connected to a three-phase power source so that the voltages on these primaries are 120° out-of-phase. The error signal is received on the primary of transformer T2. Thus, the error voltage and the reference voltage are combined in the secondary of T2.

For a less complicated example of amplifier operation with phase-shift control, let error voltage E_s be zero. This allows only the reference voltage (the AC bias) to be induced into the secondary of T2. In this situation, the relative phase relationships between component voltages are as follows:

1. The voltages at the plates of V1 and V2 are out-of-phase.

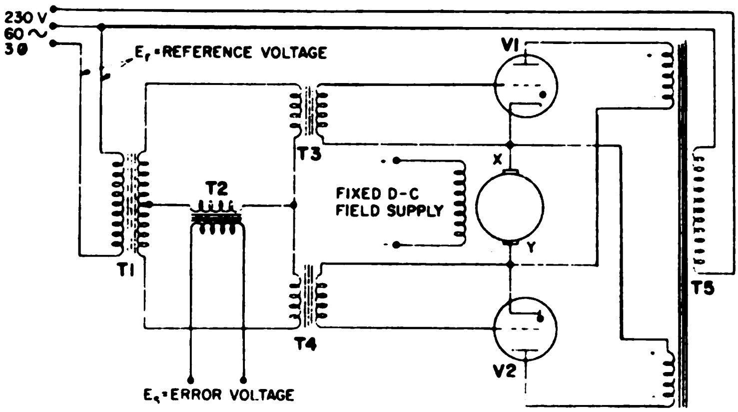
2. The voltages at the grids of V1 and V2 are equal to the reference voltage but are out-of-phase with the reference voltage.

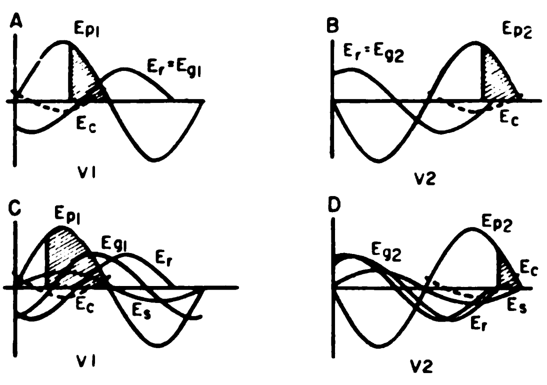
Reference voltage E_r is known to be 120° out-of-phase with plate voltages E_{p1} of V1 and E_{p2} of V2. Waveforms A and B for this condition show that V1 and V2 conduct equally during their respective positive plate alternations. Equal and opposite current pulses are applied to the armature of the servomotor; hence, there is no armature rotation.

For a second situation, let an error signal be introduced, and let E_s be in phase with E_{p1}. Waveform C illustrates how the out-of-phase summation of E_s and E_r on the grid of V1 causes a decrease in the phase lag of the resultant voltage E_{g1}, which in turn causes V1 to fire early in the positive alternation of E_{p1}. Conversely, waveform D shows how the in-phase summation of E_s and E_r on the grid of V2 causes an increase in the phase lag of the resultant voltage E_{g2}, which in turn causes V2 to fire late in the positive alternation of E_{p2}. The heavier output of V1 causes current to flow through the servomotor armature from Y to X in the illustration.

Motor rotation is reversed when the phase of the error signal is reversed, that is, when E_s is in-phase with E_{p2}.

Characteristics of the Triode Gas Tube (Continued)





122. Thyratron Phase-Shift Control System

One of the more significant features of phase-shift control is that the amount of phase shift depends upon the amplitude of the error signal. A strong error signal causes a high degree of phase shift of the resultant grid voltage, which causes a greater imbalance between the outputs of V1 and V2.

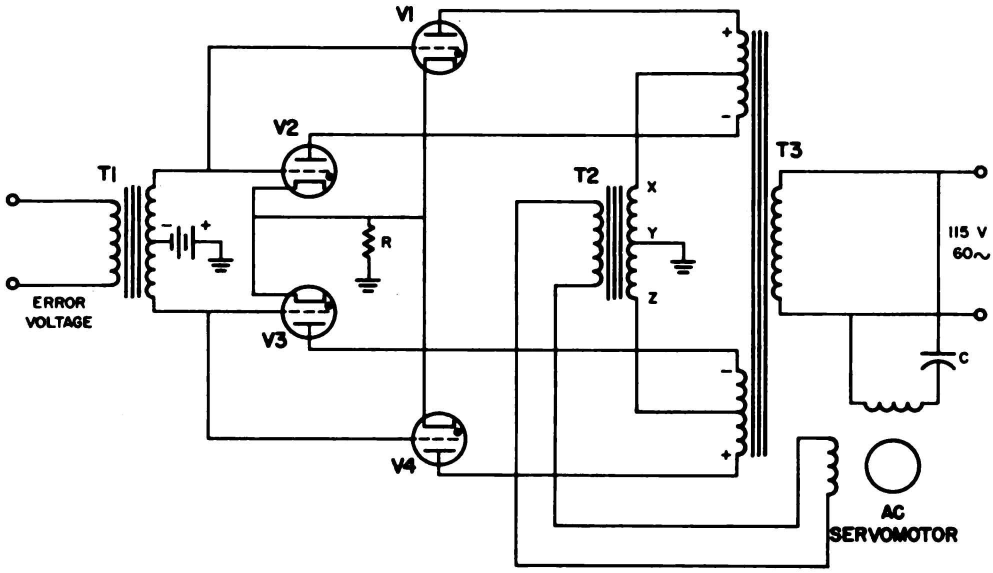
Characteristics of the Triode Gas Tube (Continued)

There are several circuit variations in which a thyratron phase-shift control is used to operate an AC servomotor. In the representative servoamplifier illustrated, transformer T3 acts as the plate supply and reference-voltage transformer. The secondary windings are arranged so that the voltages at V1 and V4 plates are in phase, as are the voltages at the plates of V2 and V3. The error voltage is applied to input transformer T1. T2 is the output transformer to the controlled-phase winding of the servomotor. If no error signal is present, none of the thyratrons fire because the negative DC grid-bias level does not intersect the critical grid bias curve.

If an error voltage appears with an instantaneous positive polarity at the top of the T1 secondary at the same time that the V1 plate swings positive, V1 fires. V2 cannot fire because its plate is negative. V4, having an additional negative bias, remains cut off. As long as the error voltage maintains this phase relationship, V2 and V4 cannot fire. On the first alternation, current flows from X to Y through the output transformer. On the following alternation, both grid and plate of V3 swing positive and V3 fires, with plate current flow from Z to Y in T2.

Thus, V1 and V3 conduct on the alternate half-cycle, causing an AC voltage to be induced into the T2 secondary. This voltage may be either in phase or out-of-phase with the reference voltage. The servomotor will now turn in the ordered direction. Reversal of the error voltage phase causes V2 and V4 to become conducting thyratrons and shifts the controlled phase 180° with respect to the reference voltage. As a result, the servomotor reverses its direction of rotation.

Characteristics of the Triode Gas Tube (Continued)

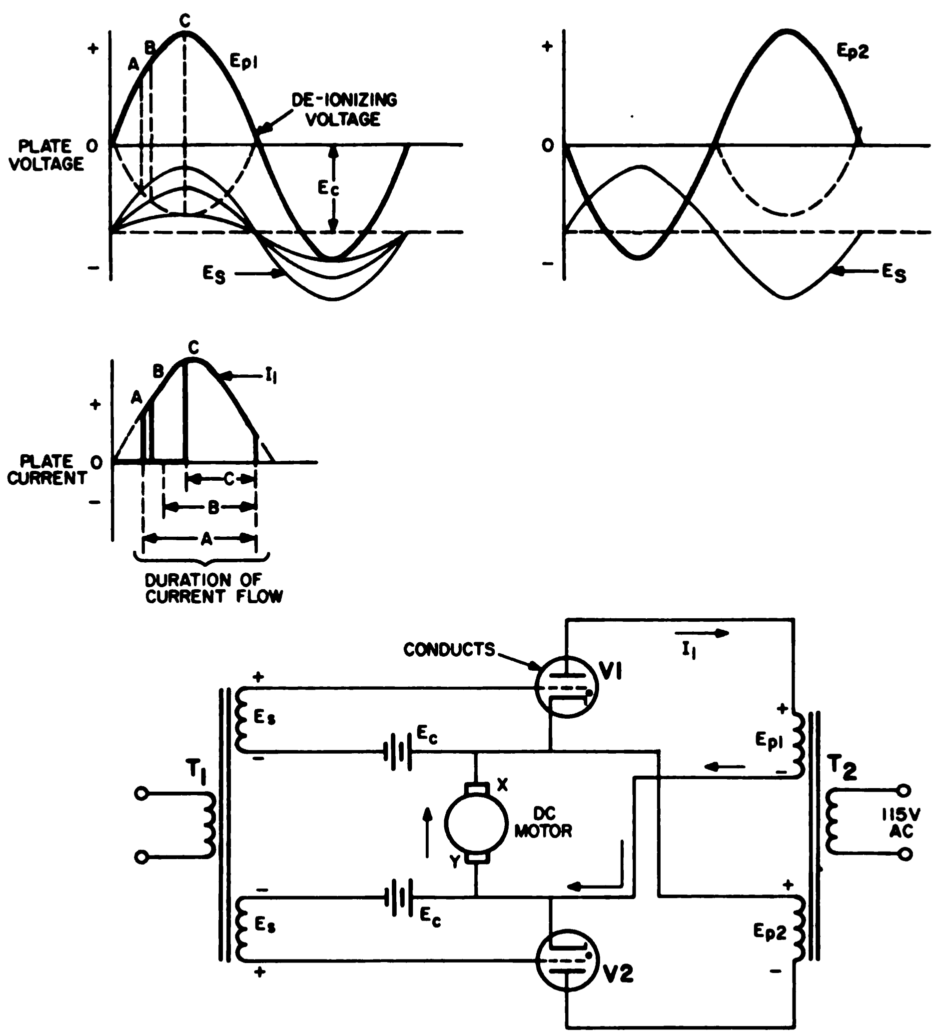


123. Thyratron Amplifier Using Common Transformer for Plate Supply and Reference Voltage

Thyratron amplifiers have certain desirable characteristics. The primary advantage of a thyratron amplifier is its larger power. The thyratron tube can handle larger load currents than can vacuum tubes of equivalent size. Phase-shift control permits the varying of the firing point of thyratrons over almost 180°, thereby improving servomotor response. When a field supply is required for a motor-generator having hundreds of horsepower, the thyratron amplifier excels because of its small inherent time delay and its efficient output voltage.

Operation of a Thyratron Servoamplifier With an Error Signal Input

Error signal E_S is the only signal applied to the grids of V1 and V2 in the illustration below. Plate voltage E_{p1} of V1 is in phase with the grid voltage E_S, but is out-of-phase with plate voltage E_{p2} of V2.



124. Schematic Diagram of Thyratron Servoamplifier Operation.

Operation of a Thyratron Servoamplifier With an Error Signal Input (Continued)

The illustrated waveforms show that E_s intersects the critical grid bias curve of V1 when the plate of V1 is positive; thus, V1 fires. In the next half cycle, E_{p2} is positive, but E_s is negative and cannot attain the critical grid bias level of V2. Consequently, V2 can never fire when E_s is out-of-phase with the plate voltage of V2.

The amplitude of E_s determines the firing time and, thus, the firing point of V1. Letters A, B, and C in the illustration designate three firing times for three different amplitudes of E_s. The resultant plate current for each of these three firing times is also shown.

Servomotor speed varies with armature current. In the illustrated situation, the armature current is the total plate current of V1. Thus, motor speed is dependent upon the amplitude of the error signal.

If the error signal reverses in phase, V2 will conduct and V1 will be cutoff. This simply means that V2 now performs as V1 did before the error signal reversed phase. Current flows through the motor in the opposite direction, thereby reversing the direction of rotation. Error signal amplitude still governs motor speed.

Applications of the Thyratron Servoamplifier to Naval Equipments

The thyratron servoamplifier is often used in speed-regulator circuits for search-radar antennas. In such applications a pair of 6.4 ampere thyratrons which control the direction and speed of a low horsepower, separately excited, DC motor are used. For low speed operation, the tubes are connected in inverse parallel like a positioning servo. For high speed operation, the tubes act as switches, operating together as a full-wave thyratron velocity servo.

When the servo is operating at low speed, it is composed of a quick-response phase detector, a DC amplifier, a phase inverter stage, and two thyratrons operating at half-wave. The error signal is obtained from a synchro after phase detection has been passed through a lead-lag network. The resulting DC voltage is added to a 90° AC lagging bias to produce proportionate control of the grid-firing angle of the two thyratrons.

Applications of the Thyratron Servoamplifier to Naval Equipments (Continued)

During high speed operation, the unit acts as a constant speed device. The circuit is a closed loop in which a portion of the counter EMF, developed in the antenna drive motor, regulates the input. This voltage is compared with an adjustable, DC-reference-voltage control, and the difference is amplified before passing through a cathode-follower stage. The output of this stage is added to the fixed AC bias voltage, which lags the plate voltage by 90°, in order to yield proportional grid control of the full-wave thyratron amplifier.

Operation of the system automatically shifts from the low speed to the high speed mode at 5 rpm with no uneven changes of speed. In addition, the usual small capacitors are connected directly from grid to cathode to filter high frequency pulses out of the grid circuit and to prevent misfiring. During switching, resistors are used to limit the negative voltage between grid and cathode to the maximum safe value prescribed by the specification for this particular type of thyratron.

Summary

The thyratron is a gas-filled, grid-controlled tube, capable of handling much greater load currents than a vacuum tube of equivalent size. It differs from the vacuum tube in three important respects.

1. Its plate-to-cathode resistance is so low in the conducting state that the voltage drop across the tube rarely exceeds 15 volts for full-rated currents.

2. Although the grid of the thyratron controls the point at which the thyratron fires (ionizes), once ionization takes place the grid loses all control and cannot stop plate current flow. As a result of this thyratron characteristic, the tube can be cut off only by lowering the plate voltage to the de-ionizing level.

3. The thyratron passes either full circuit current or no current. Therefore, while the thyratron tube acts as a rectifier, the vacuum tube may be regarded as a rheostat in series with the load. The thyratron action is that of an on-off switch. Since it is not desirable for a servomotor to jump from no speed to full speed, circuits are devised whereby the average current flow is controlled by shifting the firing point of the tube.

Summary (Continued)

Critical grid voltage is the grid voltage which permits the thyratron tube to fire. The firing time can be controlled by simply adjusting the grid bias. Increasing the grid bias causes the tube to fire later in the plate voltage cycle; decreasing the grid bias causes the thyratron to fire earlier in the plate voltage cycle. If the plate voltage is constant, the value of critical grid voltage is constant.

Thyratron tube firing can be controlled by two methods. The first method is amplitude control. Varying the amplitude of the AC grid signal will control the firing point up to 90° which is only the first half of the positive alternation of plate voltage. The second method is phase-shift control. This method provides control of the firing point over the full 180° of positive plate voltage alternation.

When an error signal is combined with the grid voltages, the resultant grid voltage causes one tube to fire earlier than the other. Plate current flows for a longer time from the conducting tube. The direction of servomotor rotation is determined by this larger current, but speed of rotation is determined by the amplitude of the error signal.

Servoamplifiers which use thyratrons have several advantages over vacuum-tube amplifiers. The primary advantage is the ability of the thyratron tube to handle larger load currents than an equivalent size vacuum tube. In addition, the ability to apply amplitude and phase-shift control increases the versatility of the thyratron servoamplifier, thereby improving the stability and response of the entire servo system.

TOPIC 8. INTRODUCTION TO THE AMPLIDYNE

You Are Now Going to Learn:

1. What the amplidyne is and how it works.
2. How the amplidyne amplifies.
3. Why electronic feedback is necessary in an amplidyne control system.
4. What the major components are in an amplidyne servo control system.

Discussion Points for This Topic Are:

1. Physical make up of the amplidyne.
2. Power amplification of the amplidyne.
3. Function of feedback in an amplidyne control system.
4. Components of an amplidyne servo system.

ASSIGNMENT:

PURPOSE:

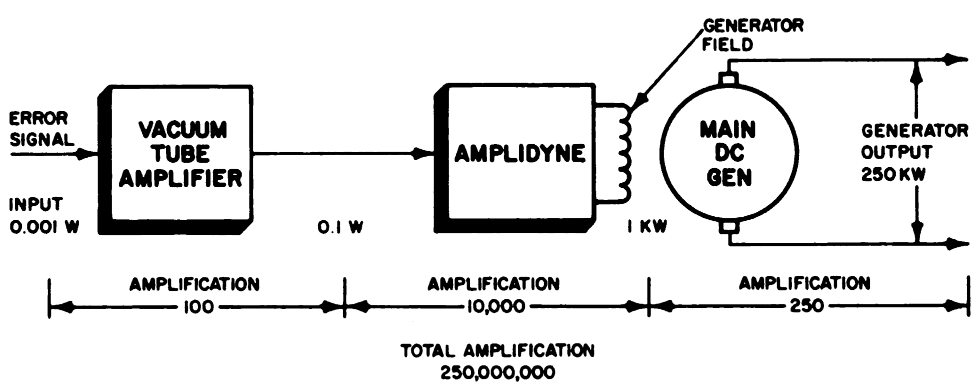
To become familiar with the characteristics and the use of the amplidyne.

TOPIC 8. INTRODUCTION TO THE AMPLIDYNE

What the Amplidyne Is and How It Works

The amplidyne, often called the amplidyne generator, is a modified and specially-wired DC generator that is driven at constant speed by an AC motor. The DC generator and the AC drive motor are contained in a single housing.

Most amplidynes use a squirrel-cage-type drive motor that has its rotor shaft coupled to the armature of the generator. This arrangement does not differ from conventional motor-generator combinations; however, the generator section of the amplidyne is modified in what might seem to be an unconventional manner. There are two sets of brushes on the commutator of the amplidyne generator; one set supplies the armature of a servomotor. but the other set is shorted. With some compensating modifications to the winding circuitry, shorting one set of brushes effectively converts the amplidyne generator into a DC amplifier with very high gain capability.

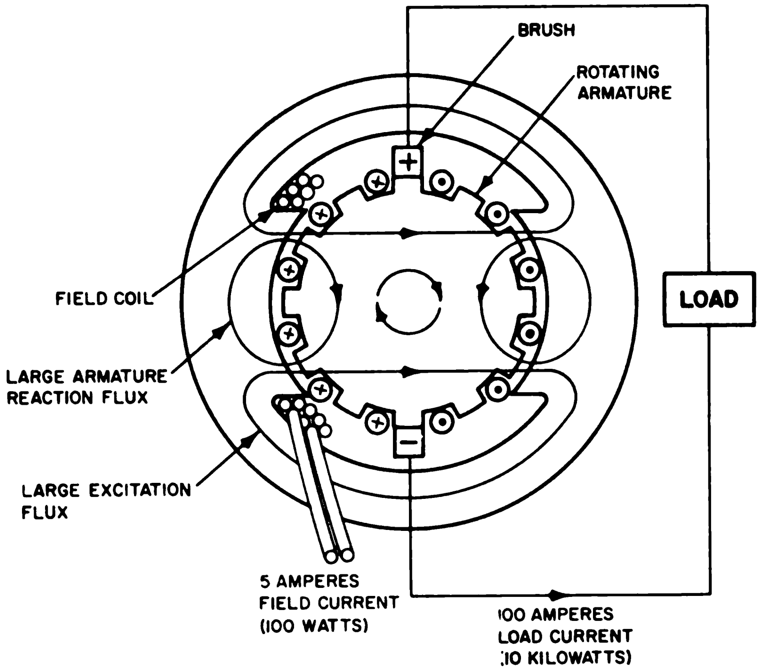


125. Partial Block Diagram of Amplidyne Drive System Emphasizing Total Amplification

The control amplifier in the above illustration performs the same function as a servoamplifier, but, since it supplies the control windings of the amplidyne generator, it is commonly referred to as the control amplifier.

Those components of an amplidyne drive system which are not included in the partial block diagram above are: the control transformer, the DC servomotor, the mechanical output, and the mechanical response to the control transformer.

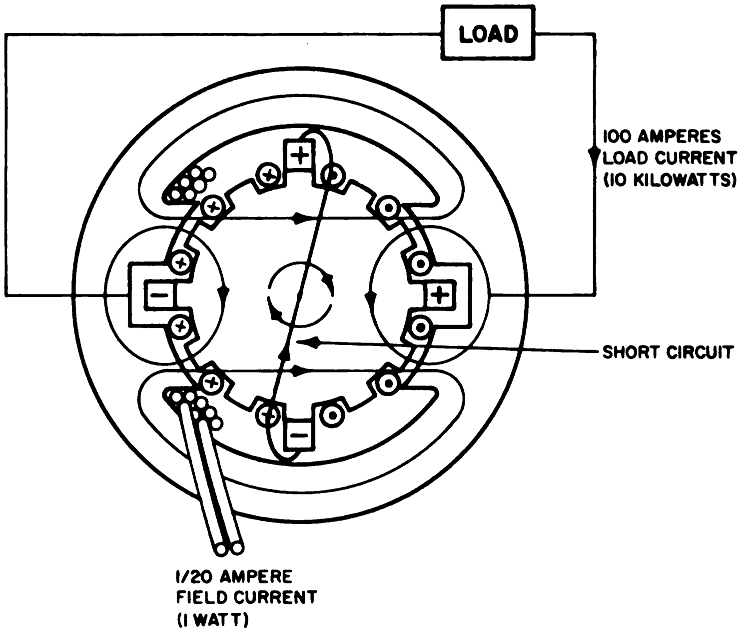
What the Amplidyne Is and How It Works (Continued)



126. Cross-Sectional Diagram of a Conventional DC Generator

As previously stated, the amplidyne generator is a modified DC generator. Essentially, two generator stages are incorporated within the single frame of the amplidyne. The first stage consists of the conventional DC generator with its one set of brushes shorted and with only about 1/20 of the conventional field-current excitation. The second stage takes advantage of the large unused armature reaction flux by the installation of a second set of brushes at right angles to the shorted set.

What the Amplidyne Is and How It Works (Continued)



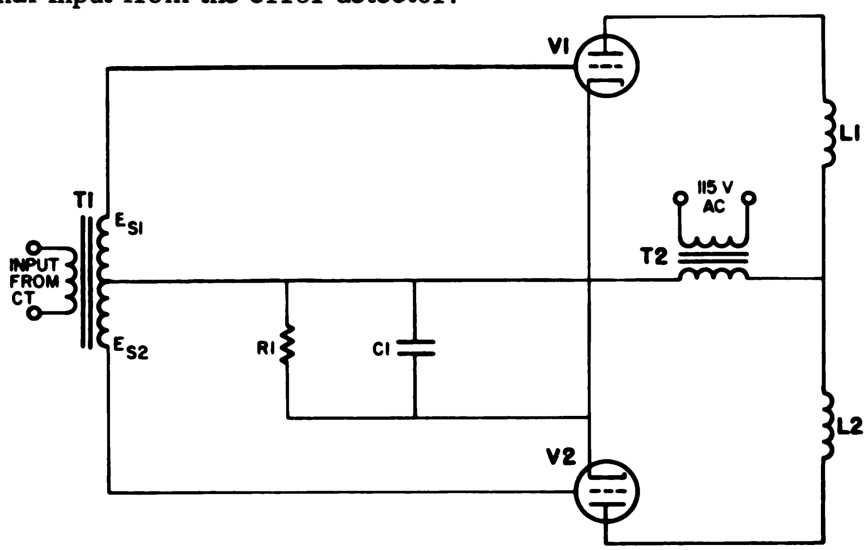
127. Cross-Sectional Diagram of an Amplidyne Generator

One of the two brushes in this second set is connected directly to the load, while the other is connected to the load through a compensating coil. The compensating coil is added to the circuitry to generate flux that opposes and nullifies the armature flux set up by the load current.

How the Amplidyne Amplifies

The real difference between a conventional DC generator and an amplidyne generator is the input to output power ratio. A DC generator capable of 10 kilowatts output must have 100 watts input. This combination is a power amplification of 100 to 1. An amplidyne generator capable of 10 kilowatts output must have an input of only 1 watt power. This combination is 10,000 to 1 power amplification. If current input to the control field of the amplidyne generator is doubled from 0.05 ampere to 0.1 ampere, the output power will be quadrupled, raising it from 10 kilowatts to 40 kilowatts.

To provide bi-directional output of the drive motor, it is necessary to split the control-field winding of the amplidyne generator. These two separate windings have equal and opposite current flow with a no-signal input from the error detector.

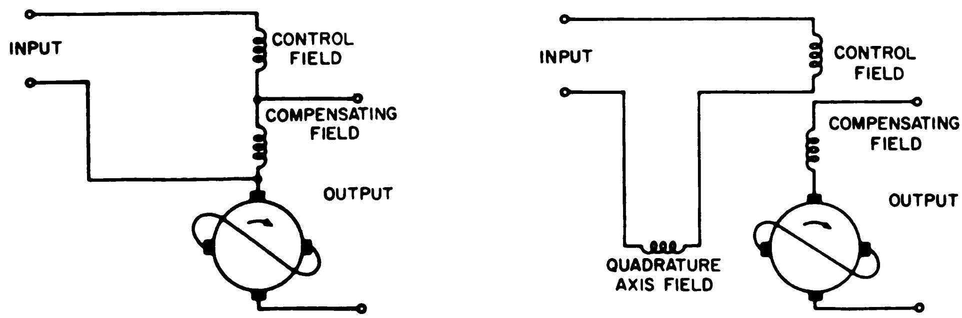


128. Control-Field Windings of Amplidyne Generator

The equal and opposite current flow across the two fields keeps the drive motor at rest. An input signal from the error detector causes an unbalance of the two tubes V1 and V2 which, in turn, causes the current in one of the control fields to rise and the current in the other to fall. The amplidyne generator produces a large power output and causes the servomotor to drive in a direction which depends upon the polarity of the input signal and at a speed which depends upon the amplitude of the input signal. Load response to this input signal is almost instantaneous.

Electronic Feedback in an Amplidyne Control System

Feedback in an amplidyne control system is accomplished in various ways. There are innumerable combinations of feedbacks for purposes of damping the output of the amplidyne generator and for canceling residual voltages built up in the amplidyne.



129. Amplidyne Generator Feedback

One common type of acceleration feedback is developed by connecting a compensating-field winding between the control-field winding and the amplidyne generator input. Because the voltage drop across the direct-axis compensating field is proportional to the output current of the amplidyne generator and because acceleration of the drive motor is also proportional to this same current, drive motor acceleration is damped.

The voltage induced in the quadrature-axis field due to changes in load impedance is another source of acceleration feedback. When acceleration varies, load impedance also varies. This action causes the quadrature-axis flux to vary, causing a voltage to be induced in the quadrature-axis windings. The induced voltage in the quadrature-axis winding affects the output current, which affects motor acceleration. Since this sequence of events is caused by a change in acceleration, it follows that the resulting actions are proportional to the amount of change in acceleration.

Electronic Feedback in an Amplidyne Control System (Continued)

Some of the larger amplidynes generate a residual voltage in the control or compensating windings; this voltage must be eliminated. This is accomplished by mounting a small, AC-excited generator on the armature shaft and connecting the output to a demagnetizing winding in the amplidyne. This is called a killer generator and cancels out most of the residual voltage.

The effect of using an amplidyne in a servo is similar to that of adding another stage of amplification to the servoamplifier except that the gain produced by the amplidyne is much higher than that likely to be produced by another stage in the amplifier.

Components in an Amplidyne Servo Control System

Two components are added to the basic servo system: the amplidyne generator and the amplidyne drive motor. The complete system will normally include an error detector with load response, amplifier, amplidyne generator, amplidyne generator drive motor, servomotor, damping generator, and feedback circuits.

Summary

Amplidyne generators are used in servomechanisms requiring high power to drive the load.

The modified DC generator known as an amplidyne is capable of power amplification of 10,000 to 1. The combination of high power amplification and a large, DC drive motor causes the load to respond quickly to small input signals.

The responsiveness of the load and the special design of the amplidyne cause stray voltages to be introduced into the servo loop. Electronic feedback and damping circuits of various kinds incorporated in the servo loop tend to nullify these oscillations and unwanted voltages.

STUDENT NOTES

TOPIC 9. DUAL-SPEED SYNCHRO-SERVO SYSTEM

You Are Now Going to Learn:

1. Speeds of synchro units and systems.
2. Automatic selection of controlling speed.
3. Importance of the stick-off transformer.
4. Advantages of a dual speed system.

Discussion Points for This Topic Are:

1. Data transmission speeds.
2. Automatic speed selection devices.
3. Stick-off voltage.
4. Dual-speed system accuracy.
5. Self-synchronization.

ASSIGNMENT:

PURPOSE:

To become familiar with the operation and the advantages of dual-speed synchro-servo systems.

TOPIC 9. DUAL-SPEED SYNCHRO-SERVO SYSTEM

Speed of Synchro Units and Systems

Data transmission speeds of synchro units are largely determined by the range of the value to be transmitted and the accuracy required at the station receiving the synchro transmission. For example, ships course transmitted from the gyrocompass to the bridge, to the Dead Reckoning Tracer, and to all weapon systems is a double-speed synchro system transmitting at 1X and 36X data transmission speeds. The total value transmitted is 360°, and the accuracy required is in minutes of arc. The gyrocompass synchro system is peculiar in that it is a double-speed and single-speed combination system. Receiver indicators at stations where less accuracy is required use only the single-speed coarse synchro system for ships course.

Data Transmission Speeds. Data transmission speeds are usually some multiple or submultiple of 36; that is, most synchro systems transmit at one or more of the following speeds:

1X, 2X, 18X, 36X, 72X, and 648X.

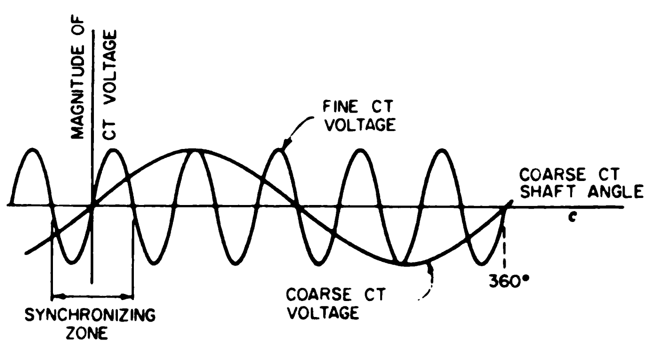
System Speeds. System speeds are single-speed, double-speed, or triple-speed. Design features of any synchro transmission system are the deciding factors that govern the data speed ratios and the system speeds in a synchro system. The degree of accuracy required by the design of the equipment utilizing the data dictates the speed of the fine control synchro to be used in the system.

Bearing, elevation, and range are the three most transmitted quantities in a Navy ship. Typical double-speed data transmission speeds used are:

bearing: 1X and 36X
elevation: 2X and 36X
range: 2X and 72X

Automatic Selection of Controlling Speed

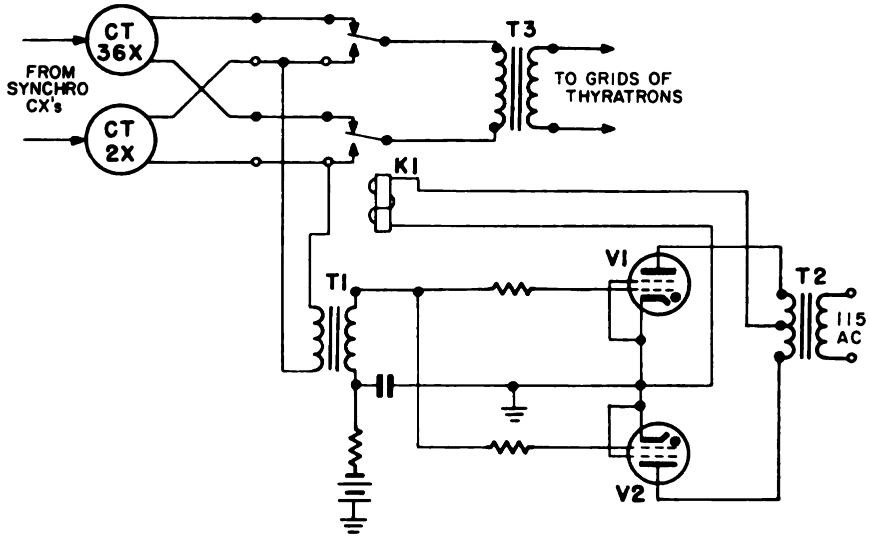
Automatic selection of either coarse or fine synchro control is necessary in dual-speed synchro systems in order to control the accuracy of servo response. This automatic selection must take place within one-half revolution on either side of the zero null of the fine control synchro.



130. Crossover Point Between Fine and Coarse Control in Dual-Speed Synchro System

Relay. The relay is one device used to select coarse or fine synchro control automatically in a dual- speed synchro system. The relay allows the coarse synchro control transformer to control the servo system until synchronization is nearly achieved. The relay then shifts control of the servo system to the fine synchro control transformer. The point at which the relay automatically shifts from coarse to fine control may vary as the characteristics of the relay coil change with age; therefore, the relay alone does not make a good automatic selector.

Automatic Selection of Controlling Speed (Continued)



131. Relay Synchronizing Circuit

The major components of the illustrated automatic selection circuit are relay K1 and thyratrons V1 and V2. The thyratrons are connected across the relay coil as shown. Plate voltage is supplied to the thyratrons by transformer T2. The thyratron grids are in phase and are supplied with the output of the two speed signal through transformer T1.

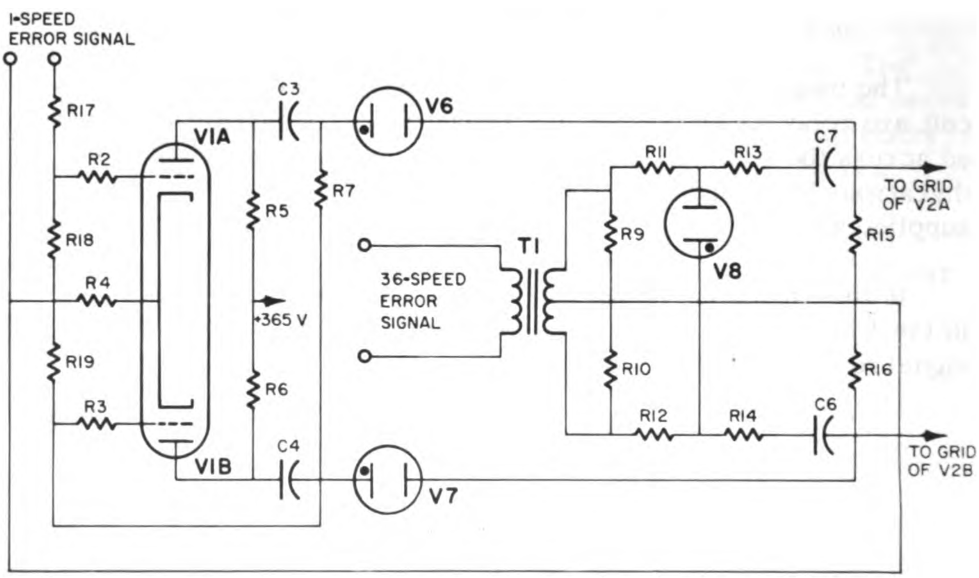
In the illustrated condition, thyratrons V1 and V2 are not conducting. Relay K1 is not energized; thus, the contacts of K1 couple the 36-speed signal to input transformer T3.

Automatic Selection of Controlling Speed (Continued)

When the two-speed error signal becomes large enough to overcome the negative bias on the thyratron grids, one of the thyratrons will fire. This conduction causes current to flow through the relay coil of K1, energizing K1. The contacts of K1 are pulled, thereby connecting the two-speed signal to input transformer T3.

When the two-speed error signal decreases (or when the output of the coarse CT approaches the synchronization point), the error signal will be too small to overcome the negative bias on the thyratron grids. The resulting increase of negative potential on the thyratron grids cannot stop ionization once it has occured; however, it can prevent ionization during the next half cycle of positive plate voltage. Nonconduction of the thyratron deenergizes K1, which then connects the 36-speed signal to input transformer T3.

Neon Tube. A neon-tube-type synchronization circuit is another means of automatically selecting coarse or fine control of a synchro-servo loop.



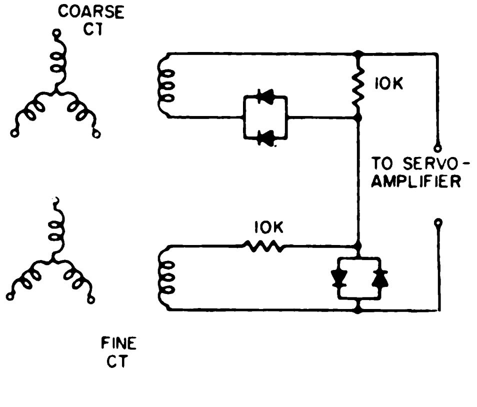
132. Neon-Tube Synchronization Circuit

Automatic Selection of Controlling Speed (Continued)

When the coarse error signal exceeds a predetermined value from synchronization, V6, V7, and V8 ionize, thereby allowing the coarse signal to be applied to the grids of V2 and, at the same time, effectively shortening the fine error signal. When the coarse error signal is decreased below this predetermined value, the voltage potential across tubes V6, V7, and V8 is insufficient to maintain ionization. The coarse error signal is opened, and the fine error signal is applied to the grids of V2.

Rectifier. Another typical automatic selection circuit is the one illustrated, which uses selenium rectifiers as the automatic selector device. When voltage across the rectifiers is large, their resistance is small. Conversely, when voltage across the rectifiers is small, their resistance is high.

When a large error signal is applied to the stators of the two control transformers, large voltages are induced into both CT rotor circuits. At this time, however, the resistance of the selenium rectifiers in both rotor circuits becomes so small that the rotor circuit of the fine CT is effectively shorted. Thus, only a small portion of the fine CT voltage is applied to the servoamplifier. The large output voltage from the coarse CT controls the servo loop until near-synchronization is reached.



133. Rectifier Synchronizing Circuit

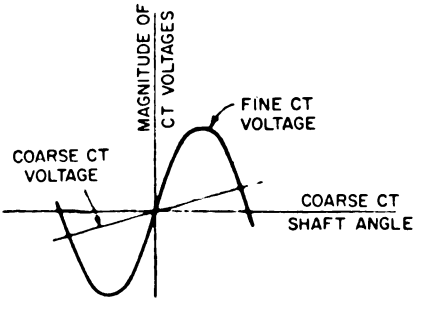
Automatic Selection of Controlling Speed (Continued)

There are some drawbacks resulting from the use of selenium rectifiers in this circuit. Selenium rectifiers act as capacitors as well as rectifiers. This capacitance causes a phase shift in the signal voltage, the amount of which will vary with the amount of voltage drop across the rectifier. Also, some of the strength of signal voltage is absorbed by the selenium rectifiers.

In similar circuits, Zener diodes have been found to be very effective as replacements for the selenium rectifiers. Circuit variations permit nullification of the capacitance offered by the Zener diodes while allowing less attenuation of signal strength.

The Stick-Off Transformer

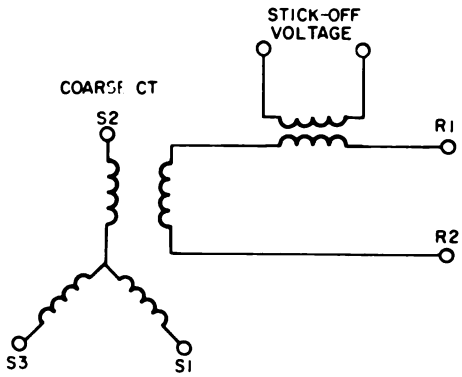
The double-speed synchro systems of most weapon systems use even gear ratios between the fine and coarse transmitters and receivers. These even gear ratios create a problem because the zero voltage output (or null condition) of both the fine and coarse control transformers occurs twice during each complete revolution of the coarse synchro. One of the two null conditions is the true synchronization point, and the other is the false synchronization point. With two apparent synchronization points, the servo loop may synchronize at either position, depending upon the electrical position of the coarse transmitter in relation to the electrical position of the coarse receiver when the system is initially energized. If the transmitter and receiver are initially displaced about 180°, the receiver will synchronize at the false null condition.



134. Crossover Zone for Synchronization

The Stick-Off Transformer (Continued)

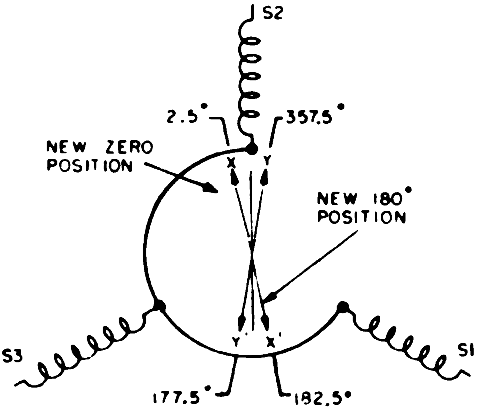
The possibility of false synchronization can be eliminated by adding a voltage in series with the rotor circuit of the coarse control transformer. This voltage is called a stick-off voltage and is produced in the secondary winding of a step-down, stick-off transformer.



135. Functional Schematic of Addition of Stick-Off Transformer

The Stick-Off Transformer (Continued)

The primary winding of the stick-off transformer is supplied by the voltage source of the synchro system. Thus, the stick-off voltage is always in phase with the signal voltage on the rotor of the coarse control transformer. The addition of this stick-off voltage to the output of the coarse control transformer does, however, necessitate the rezeroing of the synchro. No matter what speed ratio is used, the addition of stick-off voltage to the output of the coarse synchro rotor causes the zero position of the synchro to be rotated counterclockwise the equivalent (in degrees) of one-quarter turn of the fine synchro rotor. In a synchro system using a 36:1 speed ratio, for example, the zero position of the coarse control transformer rotor will be rotated 2.5° counterclockwise.



136. Synchro Zero Position With Stick-Off Voltage Applied

After rezeroing the coarse control transformer, the output voltages of both the fine and the coarse synchro will drop to zero at only one null position.

DUAL-SPEED SYNCHRO-SERVO SYSTEM

Advantages of the Dual-Speed System

The greater accuracy and the self-synchronization features of dual-speed synchro systems combine to make the use of a dual speed system more advantageous than the use of a single speed system. Either one of these two advantages compensates for the disadvantage of increased size and weight in a dual speed system. New configurations of dual-speed synchro-servo instrumentations, however, are combined in one housing. The use of these lighter and more compact instruments saves weight and space and solves a maintenance problem because the synchros in the instruments are permanently zeroed and geared to each other.

Accuracy. Accuracy of a double-speed synchro system may be improved by increasing the ratio of fine to coarse synchro speeds. For example, when using a 36:1 speed synchro system with an allowed error of 36' in the coarse synchro, the total error of the entire synchro system would be only 1' of arc. The use of two or more speeds in a data transmission system is called the "semidigital technique".

Self-Synchronization. The self-synchronous feature of the dual-speed synchro system is another advantage made possible by the automatic error selection circuits and the stick-off transformer.

Summary

The range and the accuracy of the quantity to be transmitted determine which combination of data transmission speeds should be used in a double-speed synchro system. Coarse and fine synchro speeds for a double speed system are usually designed with the fine synchro speed being some multiple of 36. For example, in a 1-and 36-speed combination, the fine synchro makes 36 revolutions to transmit the same quantitative value as one revolution of the coarse synchro.

Summary (Continued)

Circuit configurations commonly used for automatic synchro systems are the thyratron-relay circuit, the voltage rectifier or variable resistance circuit, and the neon-tube circuit. The neon-tube circuit is the most stable of the three.

Double-speed synchro systems using even gear ratios require stick-off voltage to eliminate the possibility of false synchronization. Stick-off voltage is usually added to the rotor circuit of the coarse control transformer by inserting a stepdown transformer in series with the rotor circuit. The addition of stick-off voltage necessitates the rezeroing of the coarse control transformer. After this rezeroing, however, the voltage outputs of both the coarse and the fine control transformers will be zero at only one null position.

STUDENT NOTES

TOPIC 10. THREE-SPEED SYNCHRO-SERVO SYSTEM

You Are Now Going to Learn:

1. Advantage of the three-speed synchro-servo system.
2. Functional operation of a three-speed synchro-servo system.

Discussion Points for This Topic Are:

1. Accuracy.
2. Coarse, intermediate, and fine speeds.
3. Comparator circuit.

ASSIGNMENT:

PURPOSE:

To apply the knowledge of two-speed synchro systems toward the understanding of three-speed synchro systems.

TOPIC 10. THREE-SPEED SYNCHRO-SERVO SYSTEM

Advantage of the Three-Speed Synchro-Servo System

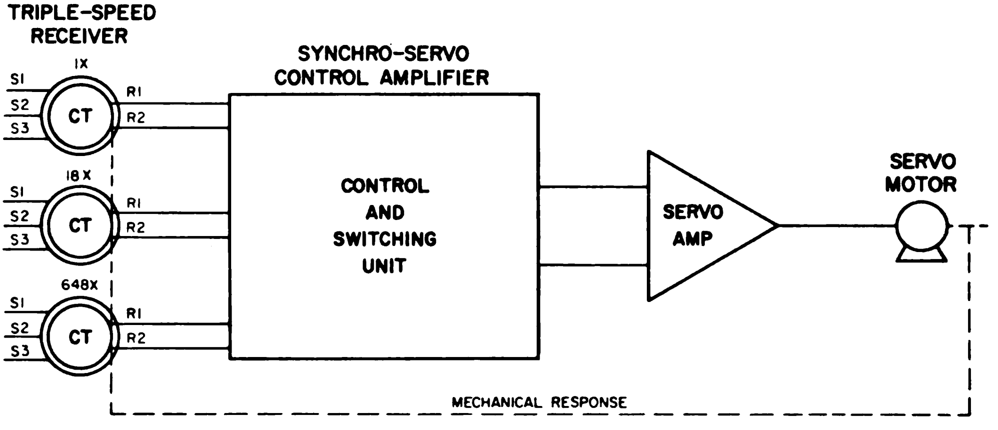
With the advent of long range missiles and high speed aircraft, a need has arisen for transmitting large values of range. For example, because of modern high speed aircraft, shipboard air-search radars are designed to detect aircraft at 500 miles. This capability is necessary to provide adequate warning in time to prepare the ships defenses against attack. As a consequence of this increased capability requirement, target designation systems also had to be redesigned so that a range of 500 miles could be designated at various combat stations.

Conventional weapons have a maximum range of about 18,000 yards. Thus, their fire control stations have no need for a range designation of 500 miles. Missiles, however, have a much greater range. Therefore, a missile fire control radar might need a range designation of at least two hundred nautical miles, which is equal to 400,000 yards.

The three-speed synchro system has made possible the transmission of large values of a quantity while maintaining high accuracy. The purpose of a three-speed synchro system is to transmit three values representing some one quantity. A calendar, for example, offers three different values of time: the year, the month, and the day. In transmitting range, a three-speed synchro system might reduce the value of range into the following units: miles, ten thousand yards, and two thousand yards. By reproducing the range quantity in three different scales, a range value can be read more accurately.

Functional Operation of a Three-Speed Synchro-Servo System

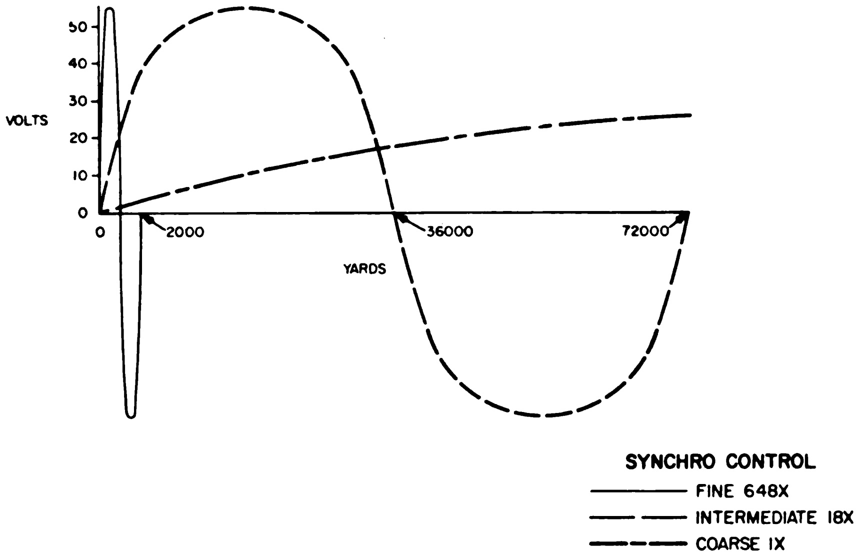
The following block diagram illustrates a three-speed synchro system used in a weapon control system to transmit range from a weapon system radar to a computer.



137. Block Diagram of a Three-Speed Synchro-Servo System

In many modern computer applications, the minimum range segment required for one revolution of the fine CT is 2,000 yards. Hence, one revolution of the illustrated 648-speed fine CT should represent 2,000 yards. For every 18 revolutions of the fine CT, the 18-speed intermediate CT makes one revolution; thus, one revolution of the intermediate CT represents 72,000 yards. Similarly, one revolution of the one-speed coarse CT represents 1,296,000 yards. Obviously, very few weapon systems have the need for a complete revolution of coarse CT output. A small segment of coarse CT output, however, can be very advantageous in long range weapon systems.

Functional Operation of a Three-Speed Synchro-Servo System (Continued)



138. Relationship of the Three CT Error Voltage Outputs in a Three-Speed Synchro System

The automatic error selection circuit that selects which of the three CT error voltages will control the servoamplifier is called a comparator. The circuit was refined from a combination of two automatic devices used for double speed selectors. Because dual-speed selection is discussed in detail in Topic 9, the comparator circuit will not be discussed in this publication. Instruction manuals for specific systems give detailed instructions for making the necessary adjustments for the correct selection of coarse, intermediate, or fine CT error signals.

Functional Operation of a Three-Speed Synchro-Servo System (Continued)

Step-by-step zeroing procedures for the illustrated synchro-servo loop are:

1. Energize the complete synchro-servo system.
2. Insure that the three synchro control transmitters are on electrical zero with range set at 10,000 yards.
3. Using a 20,000 ohms-per-volt VTVM, guide check all three control transformers for false or true null position.
4. Set the fine control transformer to electrical zero by using the VTVM method of zeroing, but set the adjustment clamps on the synchro only handtight. Do the same with the intermediate and coarse control transformers and with each rotor gear at this point.
5. Disable the coarse and intermediate selector channels.
6. Temporarily adjust the gain potentiometer to check that the servomotor will hold the fine control transformer on electrical zero. Mark this position on the rotor gear of the fine control transformer.
7. Disable the fine control transformer input by turning the gain potentiometer to zero.
8. Restore the intermediate channel, and adjust the stator of the intermediate control transformer so that the neon tube is extinguished an equal distance from either side of electrical zero.
9. Disable the intermediate channel, and restore the coarse channel.
10. Adjust the stator of the coarse control transformer so that the neon tube is extinguished an equal distance from either side of electrical zero.
11. Insure that all adjustment points are tight.
12. Restore all channels.
13. Reset gain potentiometer, and check servo loop synchronizing action.
14. Adjust receiver dials to 10,000 yards to correspond to the transmitted quantity.

THREE-SPEED SYNCHRO-SERVO SYSTEM

Summary

Close accuracy and large values of transmission are the most important advantages of using three-speed data transmission systems.

The synchros and the control circuit of any three-speed synchro system should be aligned according to the publication pertaining to that particular system. To align any multispeed synchro system, the receivers must be positioned to electrical zero in the following sequence: first, the fine receiver; second, the intermediate receiver, and last, the coarse receiver. Smooth switching and crossovers between coarse and intermediate control and between intermediate and fine control are obtained with a minimum of oscillation and hunting if proper alignment procedures are followed.

TOPIC 11. NAVAL APPLICATIONS OF AC SYNCHRO-SERVO SYSTEMS

You Are Now Going to Learn:

1. General Naval applications of synchro-servo systems.
2. One specific application of a synchro-servo system.

Discussion Points for This Topic Are:

1. Closed loop servomechanisms.
2. Power drive applications.

ASSIGNMENT:

PURPOSE:

To become acquainted with the general purposes and uses of synchro-servo systems in the Navy.

TOPIC 11. NAVAL APPLICATIONS OF AC SYNCHRO-SERVO SYSTEMS

General Applications

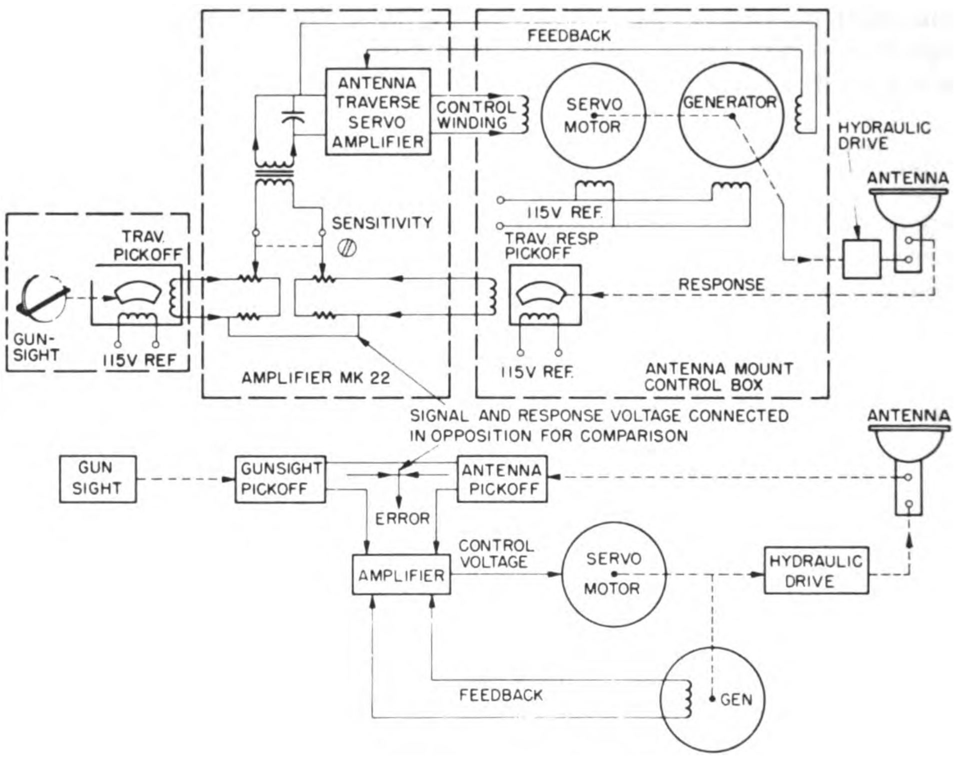
The expansion of synchro-servo system applications in the Navy is best illustrated by a comparison between one of the early computers used for gun control (which is still operational in ninety percent of the destroyers in the fleet) and the first operational computer designed to be used for missile control. The gun control computer has approximately twenty synchro-servo systems. The majority of these applications use double-speed synchro systems. The missile control computer has about forty servo loops. Approximately thirty of the loops use the output of control transformers as error voltages; the other ten use the outputs of linear potentiometers as error voltages. Synchro-servo applications have increased in each newly designed instrument used in modern weapon systems.

All closed loop servomechanisms have an error detector, a drive motor, a load, and a response. Not all servomechanisms have double-speed or triple-speed error detectors. Servo loops with only one-speed error detectors do not have automatic selector circuits, but double- or triple-speed error detectors in a servo loop must have this selection circuit. This circuit may have as its switching components neon tubes, thyratrons and relays, heart-shaped cams and contacts, selenium rectifiers or Zener diodes, or some variation of one or more of these components.

The error detector determines the difference between input signal and load position. As an error voltage, this difference is amplified and drives a servomotor in either direction, depending upon the phase of the signal as compared to the reference voltage, to nullify the error. The servomotor drives the load toward correspondence with the input signal. Mechanical response, geared from the servomotor output to the error signal source, nulls this error signal as the load moves to correspondence.

General Applications (Continued)

There are many applications of AC servomechanisms in Naval equipments. Guns, directors, radar antennas, and sonar transducers are but a few examples of the heavy loads driven by power drives that employ AC servomechanisms. The engine order telegraph, ships compass, and most computers use smaller versions of AC servomechanisms. The accompanying illustration shows the antenna drive system for the Mk 63 GFCS, one example of an AC servomechanism application.



139. Antenna Drive System for the Mk 63 GFCS

NAVAL APPLICATIONS OF AC SYNCHRO-SERVO SYSTEMS

Summary

Servomechanism applications in weapon systems, search radars, sonars, and other control systems used in the Navy have more than doubled in the past ten years.

All closed loop servomechanisms must have some type of response from the output to the input in order to null the error signal when correspondence is achieved.

TOPIC 12. TROUBLESHOOTING

<u>You Are Now Going to Learn:</u>

1. Methods of detecting casualties.
2. Methods of localizing troubles.
3. Probable causes of typical troubles.

<u>Discussion Points for This Topic Are:</u>

1. Determining the starting point for troubleshooting.
2. Checking synchro dials for casualty symptoms.
3. Troubleshooting the synchro system.

ASSIGNMENT:

Chapter 7, OP 1303 (First Revision)

PURPOSE:

To become familiar with the methods of troubleshooting, and to become acquainted with the symptoms and the probable causes of common troubles.

TOPIC 12. TROUBLESHOOTING

Troubleshooting Procedures

The procedures for troubleshooting any electromechanical instrument may be followed when troubleshooting a synchro-servo system. A systematic method of error voltage tracing must be followed from the error detector to the comparator, to the servoamplifier, and to the servomotor. Mechanical rather than electrical tracing is then continued from the output of the servomotor to the load and from the mechanical response of the load back to the error detector.

Trouble Symptoms

Symptoms of abnormal or unusual operation usually determine the starting point in any casualty analysis. Some symptoms of unusual operation may be caused by a common casualty; this particular point should be checked before proceeding with regular troubleshooting methods. Casualties frequently encountered are usually electrical rather than mechanical.

Troubleshooting procedures used on the synchro-servo training device may be followed with only slight modifications while troubleshooting any servomechanism in use aboard a ship or aircraft.

Equipment Inspection

If a casualty is indicated, the first step in systematic troubleshooting is a visual inspection of the mechanical and electrical parts of the instrument. If no casualty is apparent, the error signal should be traced from the inputs to the outputs of the major units in the servomechanism, starting with the output of the transmitter, continuing to the input signal of the receiver, then to the output leads of the error detector, and on to the input signal of the servoamplifier. This tracing is continued until the error signal is lost, at which point the casualty will be localized in a specific major unit of the servo.

TROUBLESHOOTING

Typical Troubles

Typical casualty symptoms in the synchro-servo training device and some of their probable causes are listed in the following table. Maintenance manuals written for specific types of servos will have the same types of tables.

Table 3. Probable Causes of
Common Servo System Troubles

Symptom	Casualty
Power failure	(a) Switch open or fuse blown on excitation voltage (b) Short in power transformer (c) Short in synchro transmitter rotor
No error detector output	(a) No input from control transmitter (b) Defective error detector
No servoamplifier output	(a) Defective rectifier tube 5U4 (b) No plate supply to output tubes 6L6's
Servomotor drives in one direction only	(a) Either half of 6SL7 defective (b) Either 6L6 defective (c) One secondary winding of input transformer open
Servomotor inoperative	No reference voltage excitation

TROUBLESHOOTING

Summary

The standard procedure for troubleshooting any electromechanical instrument applies when troubleshooting a synchro: the trouble must be systematically localized. Early in any casualty analysis, the troubleshooting should determine whether the trouble is electrical or mechanical.

Casualty symptoms are usually indicated by abnormal operation of the synchro dials; however, the origin of some casualties is not revealed during a visual inspection. In these instances, signal tracing may be necessary in order to localize the trouble.

STUDENT NOTES

SECTION 4

OTHER TYPES OF SERVO SYSTEMS

Topic No.	Topic Title	Page
1	Servo Loops and AC Inputs.	264
2	Servo Loops and DC Inputs.	268

TOPIC 1. SERVO LOOPS AND AC INPUTS

You Are Now Going to Learn:

1. Method of AC error detection.
2. Method of converting AC signals to DC signals.

Discussion Points for This Topic Are:

1. AC potentiometers.
2. Microsyns.
3. Servo loops with AC inputs and DC outputs.

ASSIGNMENT:

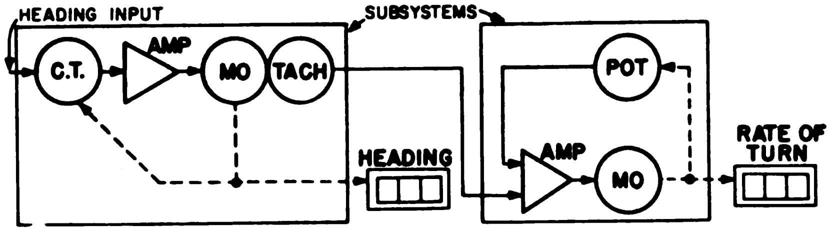
PURPOSE:

To orient the student's thinking to the system basis, concentrating on those servomechanisms having AC inputs.

TOPIC 1. SERVO LOOPS AND AC INPUTS

Error Detection

Many different types of servo loop applications are used in the Navy; however, all servo loops have the same major components: error detector, amplifier, motor, feedback, and response. The design of some of these major components varies with the design of the servo loop. For example, error detectors may be control transformers, potentiometers, pick-off transformers, resolvers, or any other type of mechanical-to-electrical position-measuring device.



140. Ships-Heading Servo Loop and Rate-of-Turn Servo Loop

The servomotor of the heading servo loop and the AC tachometer of the rate-of-turn servo loop are combined in one casting. In recent years, use of this configuration along with miniaturization has increased. In some instances, especially in aircraft applications, complete servo loops are packaged in one plug-in unit.

Servo loops using AC potentiometers as error detectors are quite common in some of the new weapon system computers. One such loop is a computing network that reduces target slant range to coordinates in the line-of-sight and across the line-of-sight.

The microsyn is another rotatable, rotor-type, position-sensing device that is used to provide an error signal input to a servoamplifier. The stator of the microsyn is usually mounted securely on the body of the instrument using the microsyn. The stator is composed of laminated steel wafers with four, eight, or twelve poles protruding toward the center of the case. The primary is series-wound around the outer section of the poles, and the secondary winding is mounted at the inner end of the poles.

Error Detection (Continued)

The guidance package of the POLARIS missile uses microsyns as error detectors. These microsyns are constructed with a sensitivity of 0.05 volts per 6 minutes of each angular rotor movement. This precision allows these instruments to be used for error detection in missile guidance system applications.

Demodulation

Not all servoamplifiers having AC inputs have AC outputs. Some applications which have AC inputs require DC outputs. In these cases, the AC input is amplified and applied to a demodulating stage. The output of the demodulator is the input to a DC servoamplifier which controls a DC servomotor.

Summary

The major components of any servo loop are the error detector, amplifier, motor, feedback, and response. Error detectors providing AC inputs to servo loops may be any type of position-measuring device. Control transformers and AC potentiometers are two such devices commonly used for error detection of AC signals.

Servomechanisms having AC inputs and requiring DC outputs require a demodulator stage preceeding a DC servoamplifier.

STUDENT NOTES

TOPIC 2. SERVO LOOPS AND DC INPUTS

You Are Now Going to Learn:

1. Common method of DC error detection.
2. Common method of converting DC signals to AC signals.

Discussion Points for This Topic Are:

1. DC potentiometer input.
2. DC amplifier instability.
3. Servo loops with DC inputs and AC outputs.

ASSIGNMENT:

PURPOSE:

To orient the student's thinking to the system basis, concentrating on those servomechanisms which have DC inputs.

TOPIC 2. SERVO LOOPS AND DC INPUTS

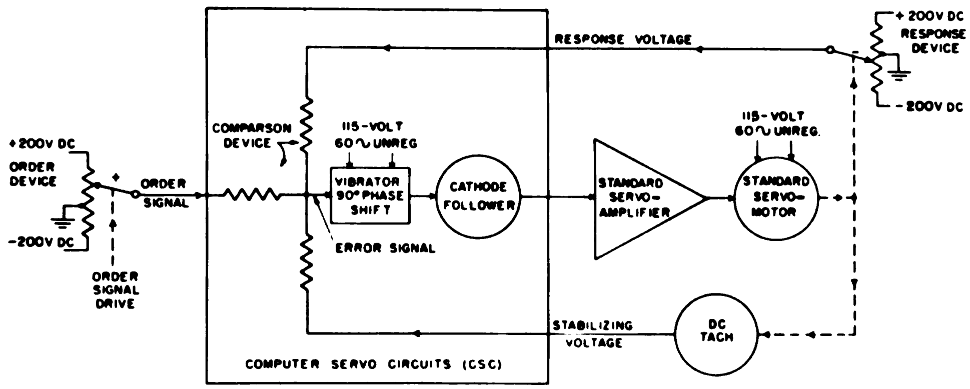
Error Detection

A major disadvantage of using a DC amplifier in a servo loop is the lack of stability. This nonstability or drift may be corrected by increasing the degenerative feedback. Good stability results only when the feedback is almost equal to the input signal. Consequently, good stability results only when unity gain is established. There are few DC servoamplifier applications because of this disadvantage.

A DC error detector is required in applications using DC servoamplifiers. One common example of a DC error detector is the potentiometer, which converts a mechanical input into a DC signal.

Modulation

Because of the disadvantages in the use of DC servoamplifiers, DC inputs to a servo are often converted to AC and are then supplied to an AC servoamplifier. One of the easiest ways to convert DC to AC is to use a vibrator. This device is also called a synchronous switch or a chopper. When placed in the line between the DC input signal and the AC reference voltage of the servoamplifier, the vibrator acts as a switch to convert the DC input to an AC square wave.



141. DC to AC Servo Loop

Modulation (Continued)

Use of the vibrator requires a 90° phase-shift circuit to be added to the servo loop because of the inherent characteristics of the vibrator device. The current in the coil that drives the vibrator lags the applied voltage, and the driven reed of the vibrator lags the driving current. The addition of the 90° phase-shift circuit compensates for these features.

The AC servoamplifier may be the conventional type, and the AC servomotor may be a standard unit. The feedback, however, is generated by a DC tachometer which is geared to the servomotor and whose output is fed back to and combined with the DC input signal. The response is also somewhat different, since it is the electrical signal from a DC potentiometer that is positioned by the mechanical output of the servomotor. This response will be of the proper polarity and magnitude to nullify the DC input signal.

Summary

One common example of a DC error detector is the potentiometer. This circuit converts a mechanical input to a DC potential.

Because of the disadvantages of using DC servoamplifiers, DC input signals are often converted to AC input signals in order to use AC servoamplifiers. The vibrator, often called a synchronous switch or a chopper, is the device commonly used to convert DC to AC.

The use of a vibrator requires the addition of a 90° phase-shift circuit in the servo loop.

PRACTICAL PROBLEMS

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Practical Problems

Part I

1. Connect a TX and a TR to form a simple torque-type synchro system.

    a. Connect S1 of the TX to S1 of the TR.
    b. Connect S2 of the TX to S2 of the TR.
    c. Connect S3 of the TX to S3 of the TR.
    d. Connect R1 of the TX and the TR to one side of a deenergized 115-volt AC source.
    e. Connect R2 of the TX and the TR to the other side of the same deenergized 115-volt AC source.
    f. Visually check steps a through e.
    g. Energize the 115-volt AC source.

2. Observe the operation of the basic torque synchro system.

    a. Observe that any movement of the TX rotor produces an identical movement of the TR rotor.
    b. Disconnect AC source.
    c. Move TR rotor $\pm$ 90°.
    d. Reconnect the AC source.
    e. Observe TR rotor movement of $\mp$ 90°.
    f. Disconnect AC source and all other connections.

3. Connect TX, TR, and TDX to form a simple torque-type synchro system with a differential unit.

    a. Connect S1 of the TX to S1 of the TDX.
    b. Connect S2 of the TX to S2 of the TDX.
    c. Connect S3 of the TX to S3 of the TDX.
    d. Connect R1 of the TDX to S1 of the TR.
    e. Connect R2 of the TDX to S2 of the TR.
    f. Connect R3 of the TDX to S3 of the TR.
    g. Connect R1 of the TDX and the TR to one side of a 115-volt AC source.
    h. Connect R2 of the TX and the TR to the other side of the 115-volt AC source.
    i. Move TX rotor and observe movement of TR rotor.
    j. Move TDX rotor and observe movement of TR rotor.
    k. Disconnect the 115-volt AC source and all other connections.

4. Connect a CX and a CT to form a simple control-type synchro system.

   a. Connect S1 of the CX to S1 of the CT.
   b. Connect S2 of the CX to S2 of the CT.
   c. Connect S3 of the CX to S3 of the CT.
   d. Connect a voltmeter between R1 and R2 of the CT.
   e. Set voltmeter for measurements on the 0-250 VAC scale.
   f. Connect a deenergized 115-volt AC source across R1 and R2 of the CX.
   g. Energize the 115-volt AC source.
   h. Move rotor of CX and observe the voltage variations on the voltmeter.
   i. Disconnect the 115-volt AC sources and all other connections.

5. Electrically zero a TX, CX, or TR by the voltmeter method, using a PSM-4 voltmeter.

Coarse Adjustment

a. With a shorting lead, short R2 to S3.
b. Using the 0-250 VAC scale, connect voltmeter between R1 and S2.
c. Connect a 115-volt AC source across R1 and R2.
d. To determine the coarse electrical-zero position of the rotor in relation to the stator, rotate either the rotor or the stator until the voltmeter indication is minimum (approximately 37 volts).
e. Without disturbing the position of the rotor in relation to the stator, disconnect the AC source and all other connections.

NOTE: If the rotor is moved, the coarse adjustment must be repeated before attempting the fine adjustment.

Fine Adjustment

a. Using the 0-250 VAC scale, connect voltmeter between S1 and S3.
b. Connect a 115-volt AC source across R1 and R2.
c. While maintaining a minimum voltmeter indication by slight adjustment of either the rotor or stator, carefully lower the voltmeter scale to the 0-5 VAC scale.
d. Position the rotor or stator for the minimum voltmeter indication.

NOTE: The rotor of the synchro is now electrically zeroed with respect to the stator.

e. Disconnect the 115-volt AC source and all other connections.

6. Electrically zero a CT by the voltmeter method, using a PSM-4 voltmeter.

Coarse Adjustment

a. With a shorting lead, short R1 to S1.
b. Using the 0-250 VAC scale, connect voltmeter between R2 and S3.
c. Connect one side of a 78-volt AC source to S3.
d. Connect the other side of the 78-volt AC source to the R1-S1 short.
e. To determine the coarse electrical-zero position of the rotor in relation to the stator, rotate either the rotor or the stator until the voltmeter indication is minimum (approximately zero volts).
f. Without disturbing the position of the rotor in relation to the stator, disconnect the AC source and all other connections.

NOTE: If the rotor is moved, the coarse adjustment must be repeated before attempting the fine adjustment.

Fine Adjustment

a. With a shorting lead, short S1 to S3.
b. Using the 0-250 VAC scale, connect voltmeter between R1 and R2.
c. Connect one side of a 78-volt AC source to the S1-S3 short.
d. Connect the other side of the 78-volt AC source to S2.
e. While maintaining a minimum voltmeter indication by slight adjustment of either the rotor or stator, carefully lower the voltmeter scale to the 0-5 VAC scale.
f. Position the rotor or stator for the minimum voltmeter indication.

NOTE: The rotor of the CT is now electrically zeroed with respect to the stator.

g. Disconnect the 78-volt AC source and all other connections.

7. Electrically zero a TDX by the voltmeter method, using a PSM-4 voltmeter.

Coarse Adjustment

a. With a shorting lead, short S1, S3, R1, and R3.
b. Using the 0-250 VAC scale, connect voltmeter between R2 and R3.
c. Connect one side of a 78-volt AC source to S2.
d. Connect the other side of the 78-volt AC source to the S1-S3-R1-R3 short.
e. To determine the coarse electrical-zero position of the rotor with respect to the stator, rotate either the rotor or stator until the voltmeter indication is minimum.
f. Without disturbing the position of the rotor in relation to the the stator, disconnect the AC source and all other connections.

NOTE: If the rotor is moved the coarse adjustment must be repeated before attempting the fine adjustment.

Fine Adjustment

a. With a shorting lead, short S1 to S3.
b. Using the 0-5 VAC scale, connect voltmeter across R1 and R3.
c. Connect one side of a 78-volt AC source to S2.
d. Connect the other side of the 78-volt AC source to the S1-S3 short.
e. Position the rotor to obtain the minimum voltmeter indication.

NOTE: The rotor of the TDX is now electrically zeroed with respect to the stator.

f. Disconnect the 78-volt AC source and all other connections.

Practical Problems

Part II

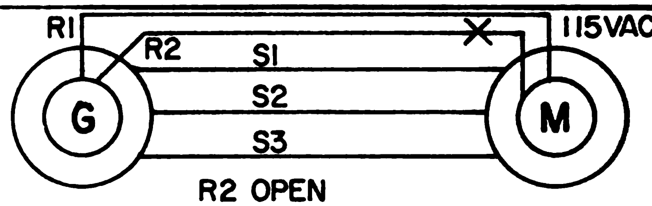
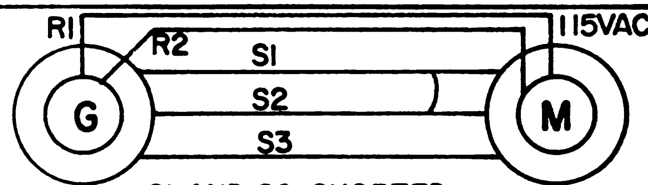
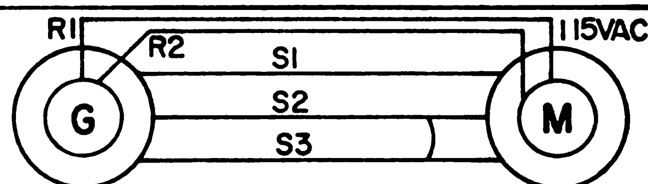
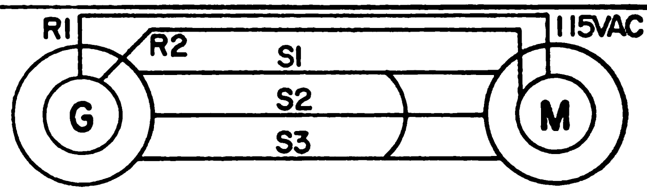
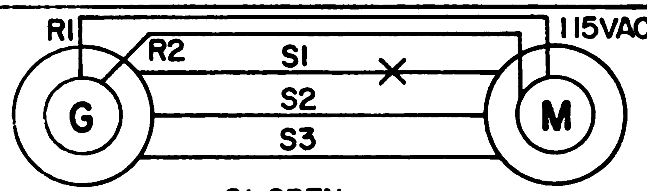
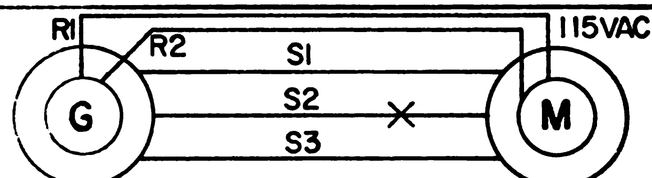
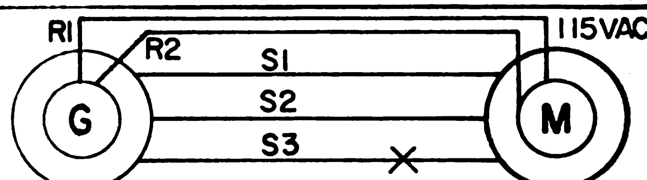
1. Using the synchro training board, connect units to form a simple synchro system.

   a. Connect lead S1 of TX to lead S1 of TR.
   b. Connect lead S2 of TX to lead S2 of TR.
   c. Connect lead S3 of TX to lead S3 of TR.
   d. Connect both R1 leads of TX and TR to one side of 115-volt AC source.
   e. Connect both R2 leads of TX and TR to other side of 115-volt AC source.

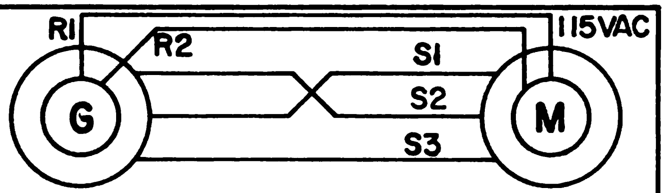
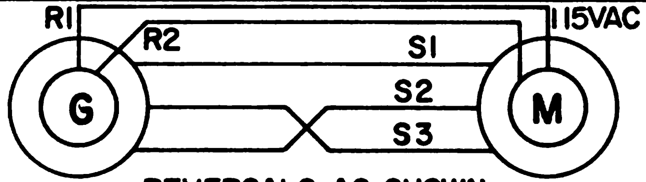
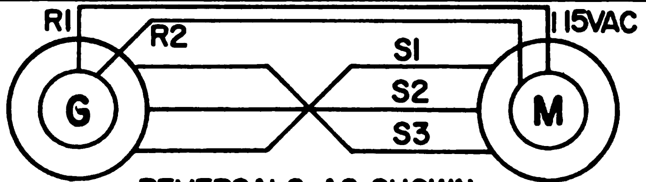
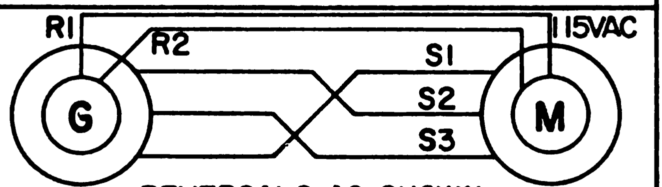
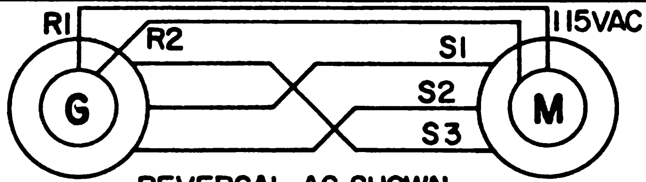
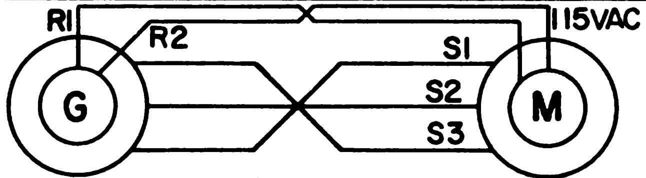
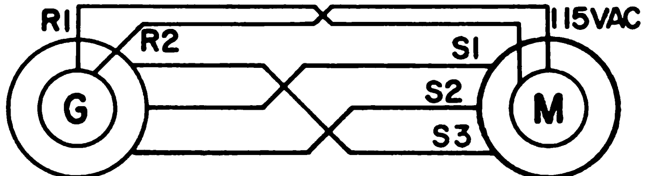
2. Troubleshooting procedures.

   The trainee will perform the 14 operations outlined in the synchro-troubleshooting work sheets. As each casualty is introduced, the trainee will observe the actions of the units and make notations as to dial rotation, rotor torque, etc. The 115-volt AC source will be disconnected prior to introducing each of the casualties.

SYNCHRO TROUBLESHOOTING WORKSHEET

1			 R2 OPEN
2			 S1 AND S2 SHORTED
3			 S2 AND S3 SHORTED
4			 S1 AND S3 SHORTED
5			 S1 OPEN
6			 S2 OPEN
7			 S3 OPEN

SYNCHRO TROUBLESHOOTING WORKSHEET

8			 REVERSALS AS SHOWN
9			 REVERSALS AS SHOWN
10			 REVERSALS AS SHOWN
11			 REVERSALS AS SHOWN
12			 REVERSAL AS SHOWN
13			 REVERSAL AS SHOWN
14			 REVERSAL AS SHOWN

Practical Problems

Part III

1. Operate the two channels of the synchro-servo training device.

    a. Connect the S1, S2, and S3 leads from the TR on the synchro-servo training board to the S1, S2, and S3 leads of the CT on the synchro-servo training device.
    b. Energize the synchro training board and the synchro-servo training device by connecting their plugs to a 115-volt AC outlet.
    c. Rotate the rotor of the TR on the synchro training board and observe the output of channel one of the synchro-servo training device.
    d. Vary the setting of the input potentiometer on the synchro-servo training device and observe the output of channel two.

2. Trace a signal through the synchro-servo training device.

    Channel One

    a. The input originates in the TR of the synchro training board and is transmitted to the stator of the CT of the synchro-servo training device.
    b. The error signal is transferred from the rotor of the CT to the range servoamplifier and is amplified.
    c. The amplified signal is coupled through a transformer to the servomotor. Feedback for the range servoamplifier is taken from the transformer.
    d. Mechanical response from the range servomotor repositions the rotor of the CT and nulls the error signal.

Channel Two

a. The error signal originates in the variable potentiometer and is felt in the primary of T3.
b. The error signal is coupled from the primary of T3 to the secondary of T3 and then to the range-rate servoamplifier and is amplified.
c. The amplified signal is coupled through another transformer from the range-rate servoamplifier to the range servomotor. The feedback for the range-rate servoamplifier is taken from the transformer.
d. Mechanical response from the range-rate servomotor positions a nulling potentiometer which provides the voltage necessary to null the error signal.

STUDENT NOTES

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